Disc Working Group

Challenges 2014

- Local Dark Matter Density
- Pattern speed of the arm and spiral Arm
- Identifying Stellar Motions associating different Spiral Arm Science
- Collaborations:
  Eugene Vasiliev + Besancon galaxy model (BGM)
  adding more self-consistent dynamical model to BGM

Local Dark Matter Density with Non-Parametric Mass Modeling

Hamish Silverwood & Sofia Sivertsson,
Gianfranco Bertone (GRAPPA, UvA)
Pascal Steger (ETH Zurich)
Justin Read (University of Surrey)

GRAPPA
GRavitation AstroParticle Physics Amsterdam

Aims

- Determination of the local dark matter density and its uncertainty, using as few assumptions as possible.
- Critical for limits from direct detection of dark matter:

First results from the LUX dark matter experiment at the Sanford Underground Research Facility

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Introduction - LUX Dirrect Detection

Image: DESY/Milde Science Comm./Exozet

Direct Detection Assumptions

The energy spectrum of WIMP-nucleus recoils is modeled using a standard isothermal Maxwellian velocity distribution [38], with $v_0 = 220$ km/s; $v_{esc} = 544$ km/s; $\rho_0 = 0.3$ GeV/cm^3; average Earth velocity of 245 km s^{-1}, and Helm form factor [39, 40]. We conservatively model no signal below 3.0 keV$_{nr}$ (the lowest energy for which a direct light yield measurement exists [30, 41], whereas indirect evidence of charge yield exists down to 1 keV$_{nr}$ [42]). We do not profile the unce
in NR yield, assuming a model which provides
agreement with LUX data (Fig. 1 and Fig. 6), in
to being conservative compared to past works
also do not account for uncertainties in astr
parameters, which are beyond the scope of this w
are discussed in [43]). Signal models in S1 an
obtained for each WIMP mass from full simulat

Lewin & Smith, Astroparticle Physics 6 (1996) 87-112

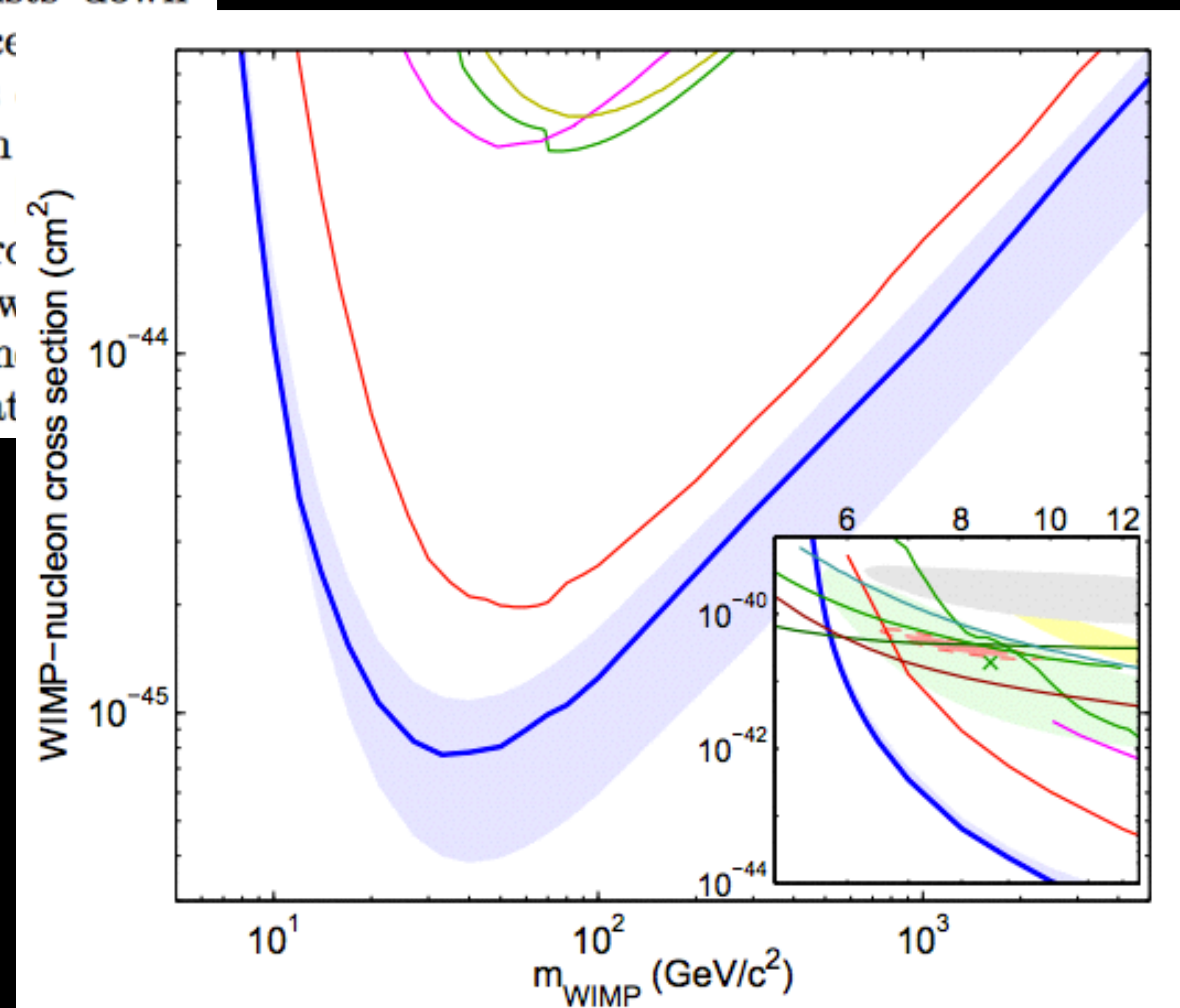


Image: DESY/Milde Science Comm./Exozet

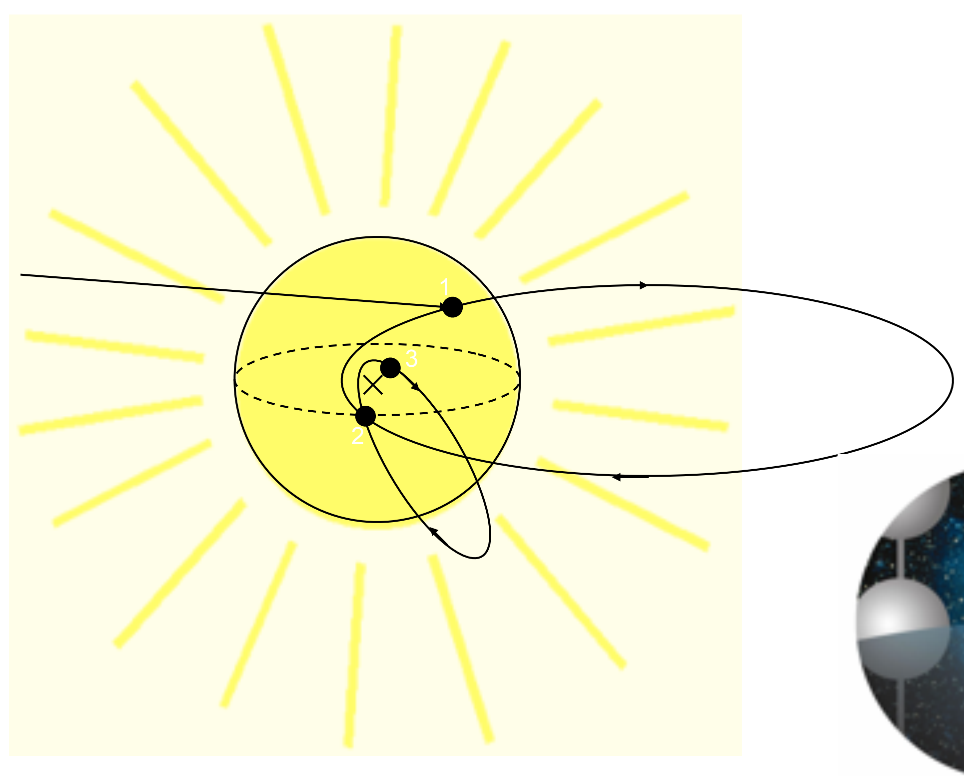
Dark Matter Disc & Dark Matter Indirect Detection

- The galactic stellar/gas disc causes merging satellites to be dragged preferentially towards the disc plane, where they are torn apart by tides.

- Gives a co-rotating dark matter disc of density ~0.25-1.5 times the non-rotating halo density. [Read et.al. 2009]

- Due to its low relative velocity, such a dark matter disc would be of utmost importance for WIMP dark matter indirect detection with neutrinos.

- Boosts the neutrino signal from the Sun by a factor of ~10 and from the Earth by a factor of ~1000.



IceCube

NIKHEF

Experimentalists

ITFA - Institute for Theoretical Physics Amsterdam

Direct Detection, e.g. XENON100/1T

Indirect Detection e.g. ANTARES/KM3NET neutrino telescopes

Exploration of Theoretical Parameter Space, e.g. Supersymmetry

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Astronomy

ASTRONOMICAL INSTITUTE
ANTON PANNEKOEK

Method

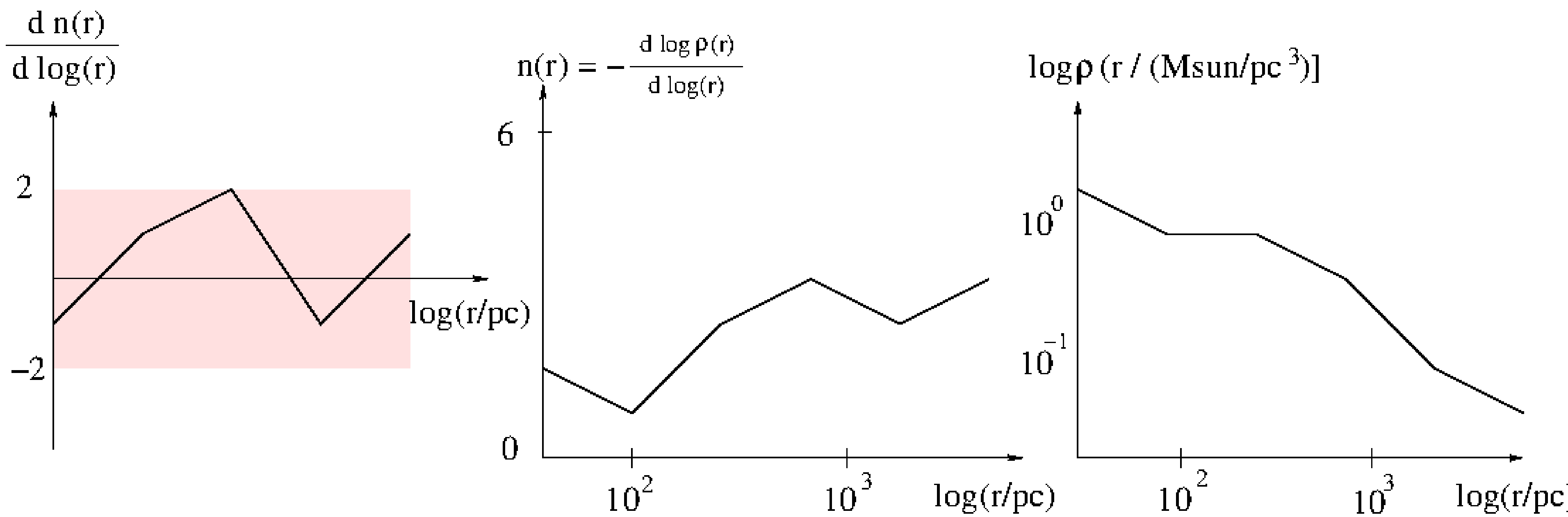
Pascal Steger's talk yesterday:

ETH zürich

Non-Parametric Jeans Modelling

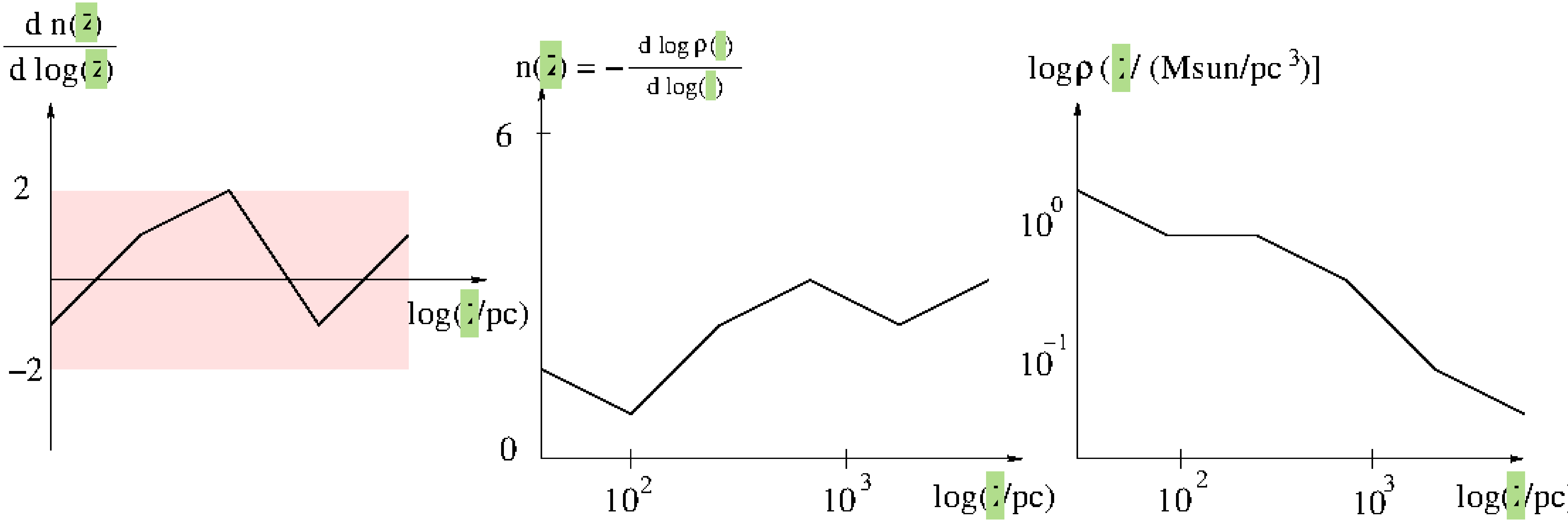
$$\rho(r) = Ar^{-n(r)}, \qquad n(r) = -\frac{\mathrm{d}\log\rho(r)}{\mathrm{d}\log r}$$

$$\rho(r) = \rho_{1/2}\cdot\exp\left[-\int_{\log r_{1/2}}^{\log r} n(s)\mathrm{d}s\right]$$



Method - Radial to Vertical

Pascal Steger's talk yesterday:



Instead of modelling mass in radial bins, model mass in vertical bins above/below the galactic plane.

Use this to model
- tracer density
- Dark Matter mass density
- Baryonic mass density

Method - Jeans Analysis

z-Jeans Equation:

$$\underbrace{\cancel{\frac{1}{R\nu}\frac{\partial}{\partial R}\left(R\nu_i\sigma_{Rz}\right)}}_{\text{`tilt' term: }\mathcal{T}} + \frac{1}{\nu}\frac{d}{dz}\left(\nu\sigma_z^2\right) = \underbrace{-\frac{d\Phi}{dz}}_{K_z}$$

Assume zero Tilt term

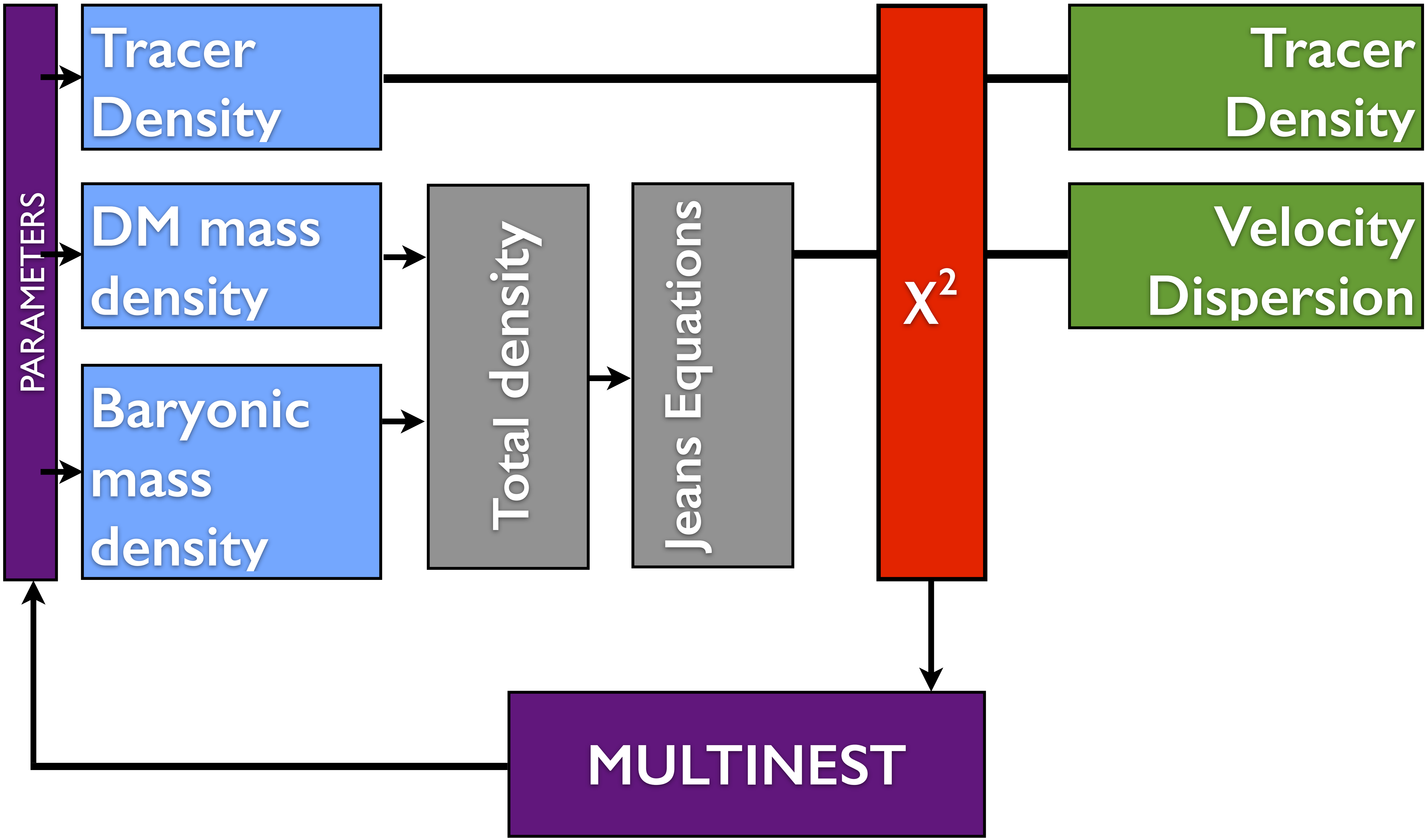
Integrate

$$\sigma_z^2(z) = \frac{1}{\nu(z)}\int_{z_{\min}}^{z} \nu(z')\left[K_z(z') - \cancel{\mathcal{T}(z')}\right] dz' + \frac{C}{\nu(z)}$$

Poisson Equation, standard Newtonian gravity

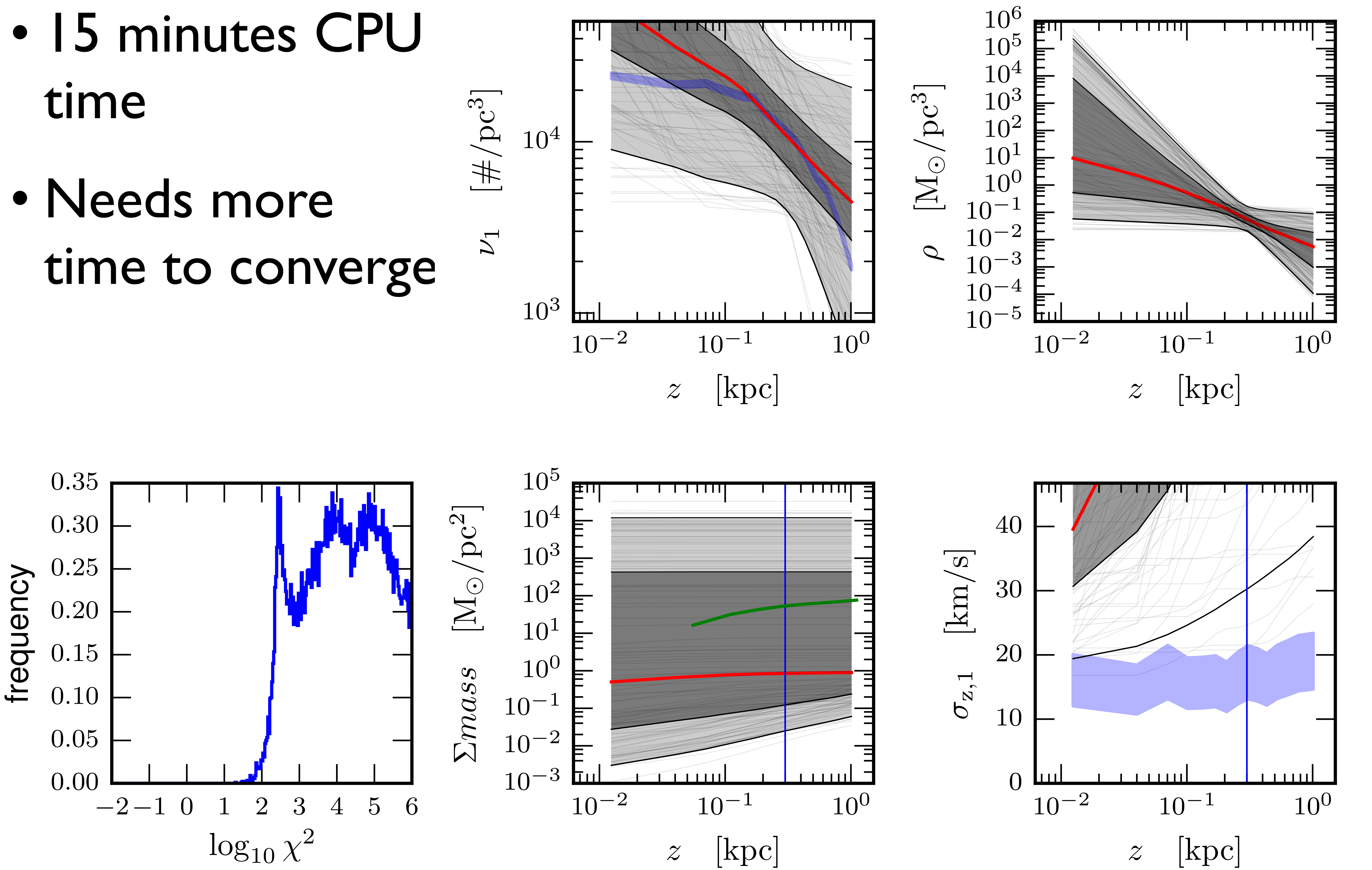
$$\nabla^2\Phi = \frac{\partial^2\Phi}{\partial z^2} + \underbrace{\frac{1}{R}\frac{\partial V_c^2(R)}{\partial R}}_{\text{`rotation curve' term: }\mathcal{R}} = 4\pi G\rho \xrightarrow[\text{zero R-term}]{\text{Integrate, assume}} \Sigma_z(z) = \frac{|K_z|}{2\pi G}$$

Method - Analysis Flow



Results - Very Preliminary

- 15 minutes CPU time
- Needs more time to converge



Roadmap

- Get method fully working on Justin Read's 1D mock data
- Determine level of data needed to distinguish DM from baryonic, distinguish a dark disk
- Apply to SDSS RAVE data
- Release assumptions e.g. reintroduce tilt term, rotation term
- Introduce more detailed baryonic models and observational constraints.
- Move to 2D, and eventually 3D
- Introduce Gaia error modeling

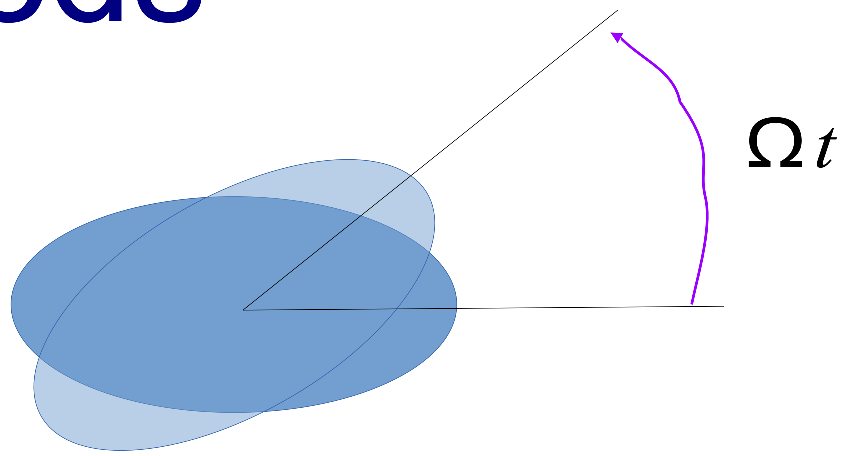
Pattern Speed of the Bar (and Spiral Arms)

Laurent Chemin, Daniel Pfenniger, Merce Romero-Gomez,
Jason Hunt, Daisuke Kawata

- Objective
  Recovering Bar and Pattern speed from Mock data

- Method
  Local Tremaine-Weinberg method: using grid and SPH derivatives
  M2M: PRIMAL

Pattern speeds



- What is a pattern ?
- Definitions :
  - A pattern is a function of coordinates that is constant in time through a rotation proportional to time.
  - The pattern speed is the angular speed that keeps the pattern constant.
- Remarks :
  - Different patterns may lead to different pattern speeds
  - Bars and spirals are not rigid bodies

Pattern of modes

- Example :
  - Fourier transform of mode *m* of a ring of particles

$$F(m) = F_R(m) + j\, F_I(m) = \sum_{i=1}^{N} w_i \left[\cos(m\, a(t)) + j \sin(m\, a(t))\right]$$

$$a(t) = \arctan(y_i(t), x_i(t))$$

mode phase :

$$\phi = \arctan(F_I(m), F_R(m))$$

$$\Rightarrow$$

$$\boxed{\Omega = \frac{d\phi}{dt} = \frac{m}{|F(m)|^2} \sum_{i=1}^{N} w_i \left[F_R(m)\cos(m\, a_i) + F_I(m)\sin(m\, a_i)\right] \frac{L_i}{R_i^2}}$$

Local TW method

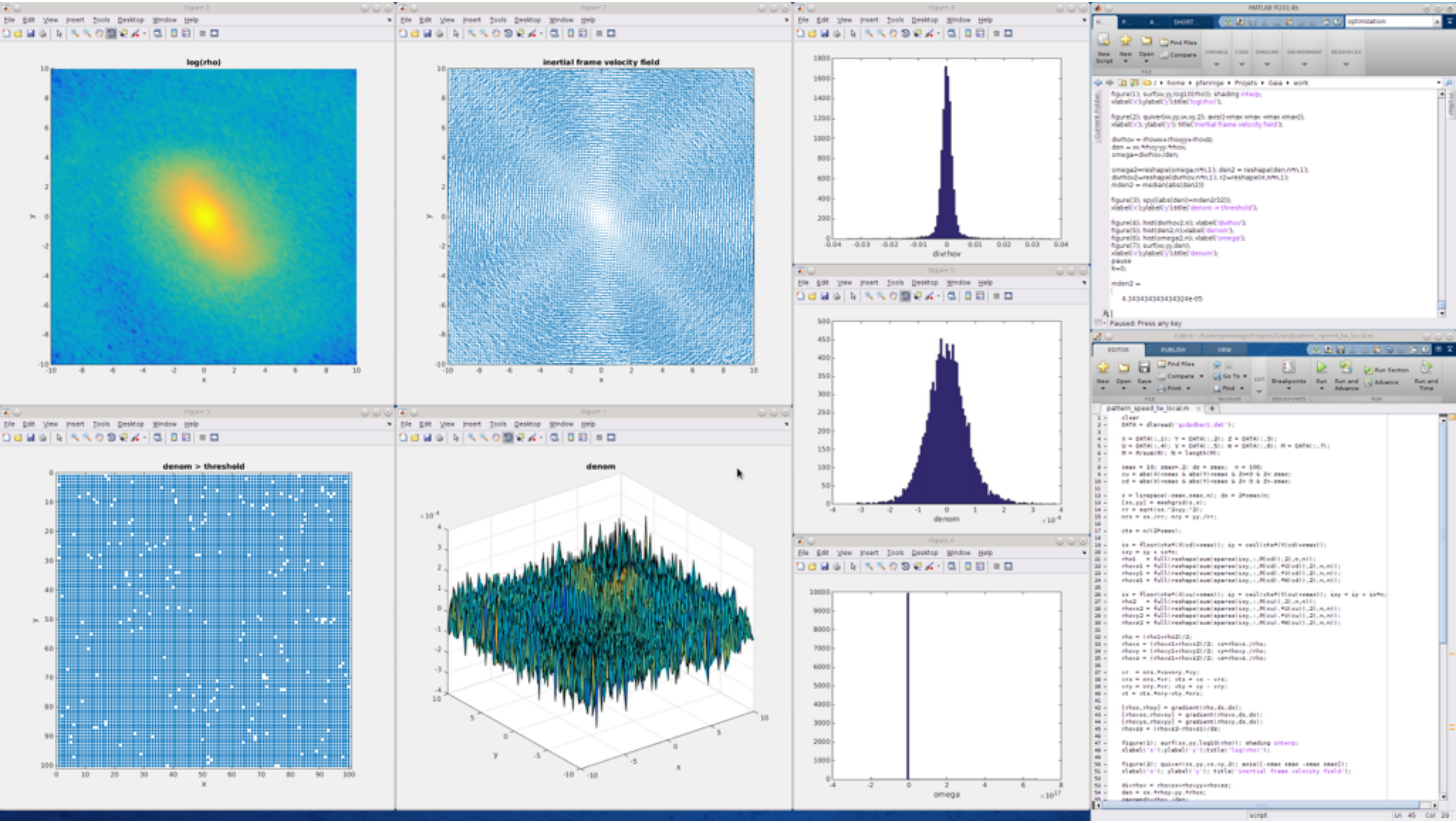
- Density gradients define shapes. Using continuity equation Tremaine & Weinberg (1984) deduced a global pattern speed formula
- Advantage:
  - Radial velocity component sufficient for external galaxies
  - No gradient required
- Problems:
  - galaxies may have distinct patterns at different locations
  - Unsuited for MW
- However the local formula holds

$$\Omega_p = \frac{\nabla \cdot (\rho \vec{v})}{x \partial_y \rho - y \partial_x \rho}$$

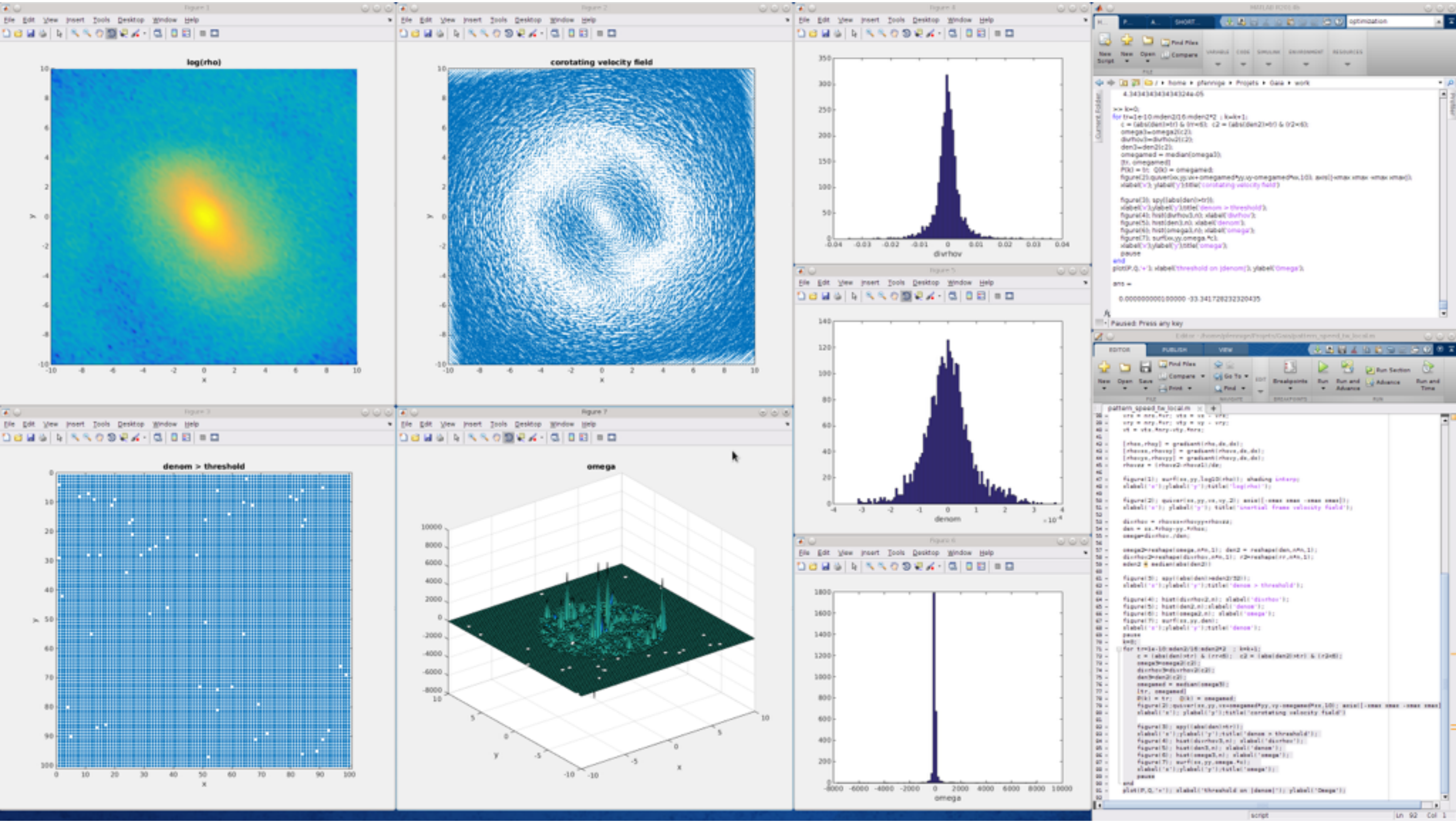
Local TW method

- Repeat Laurent Chemin analysis of the Daisuke Kawata N-body sample (1 M particles)
- Matlab code (1 page)
- Pattern speed of the bar -32 km/s/kpc
- Pattern speed of the spiral -21 km/s/kpc

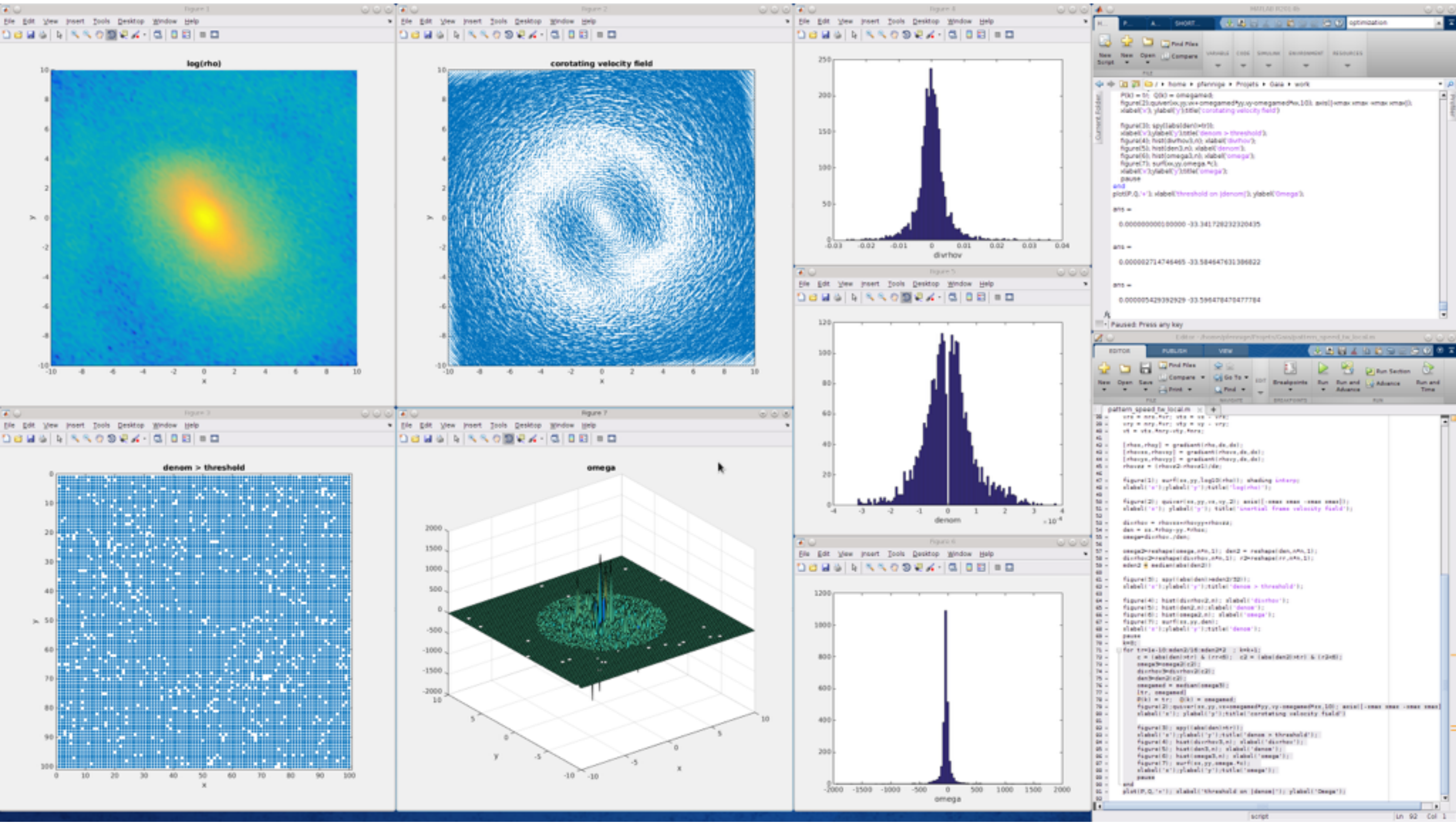
Small denominator => problems



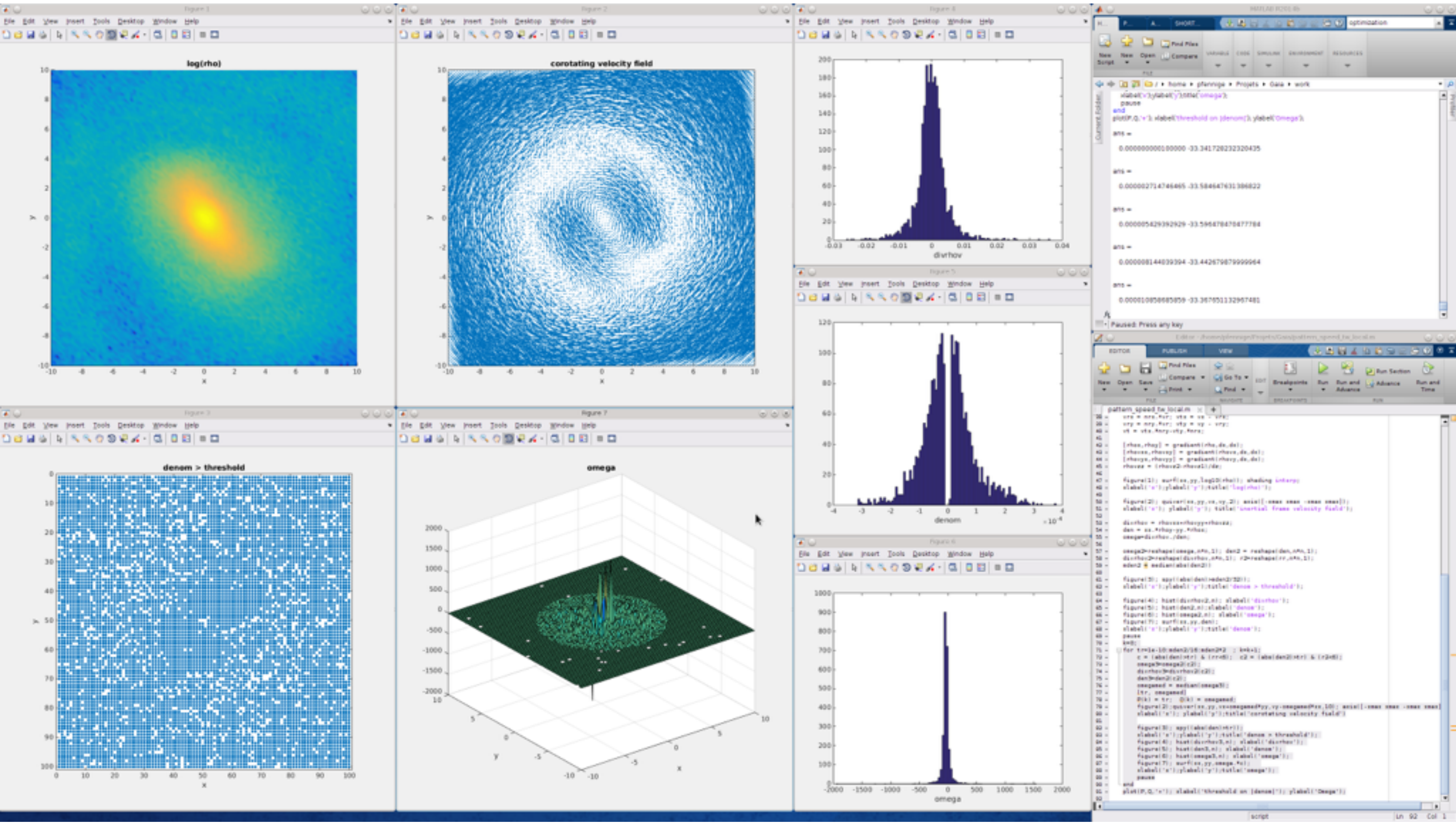
|Den| > 1e-10, much better



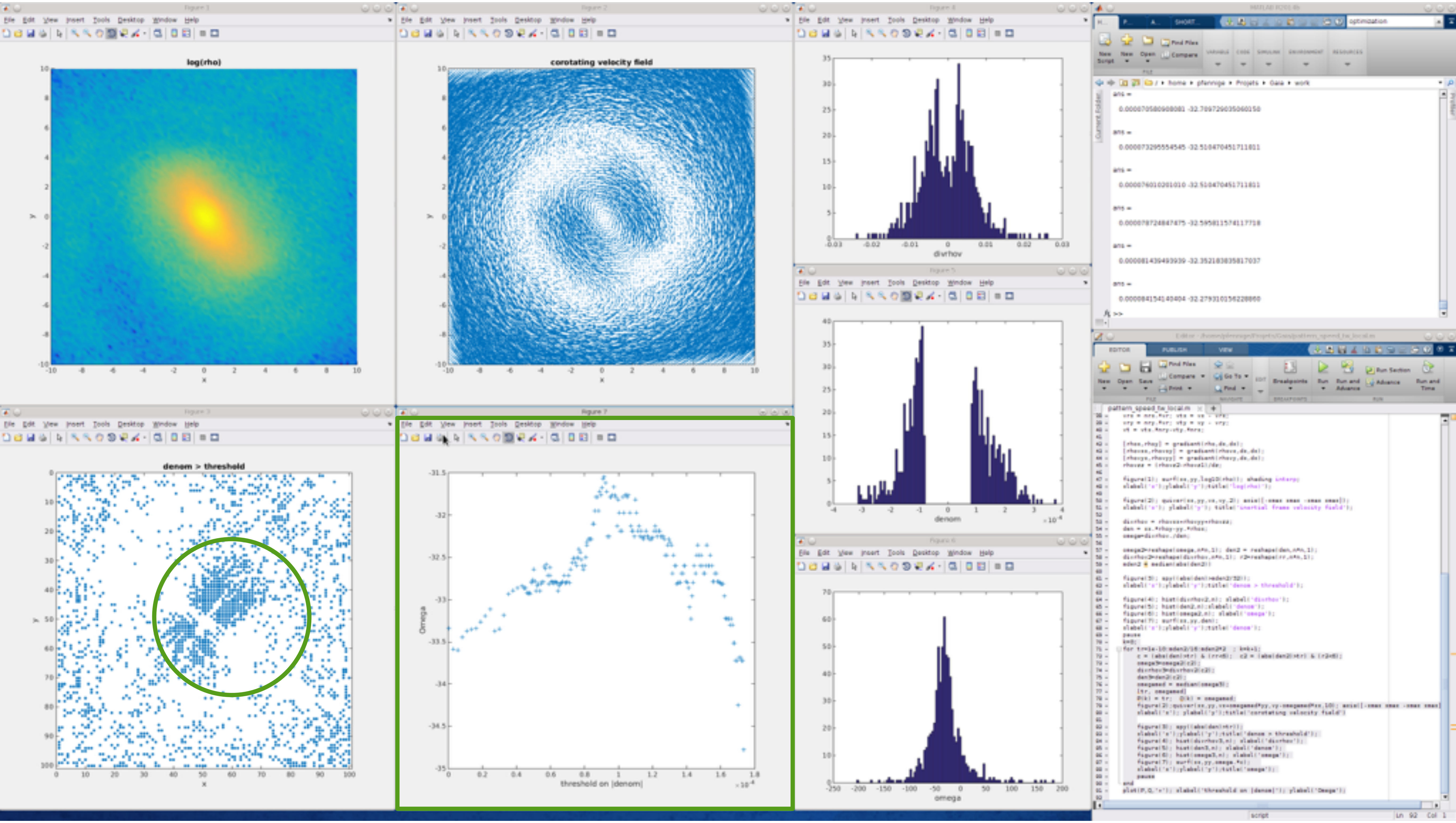
Median Omega is robust



Median Omega is robust



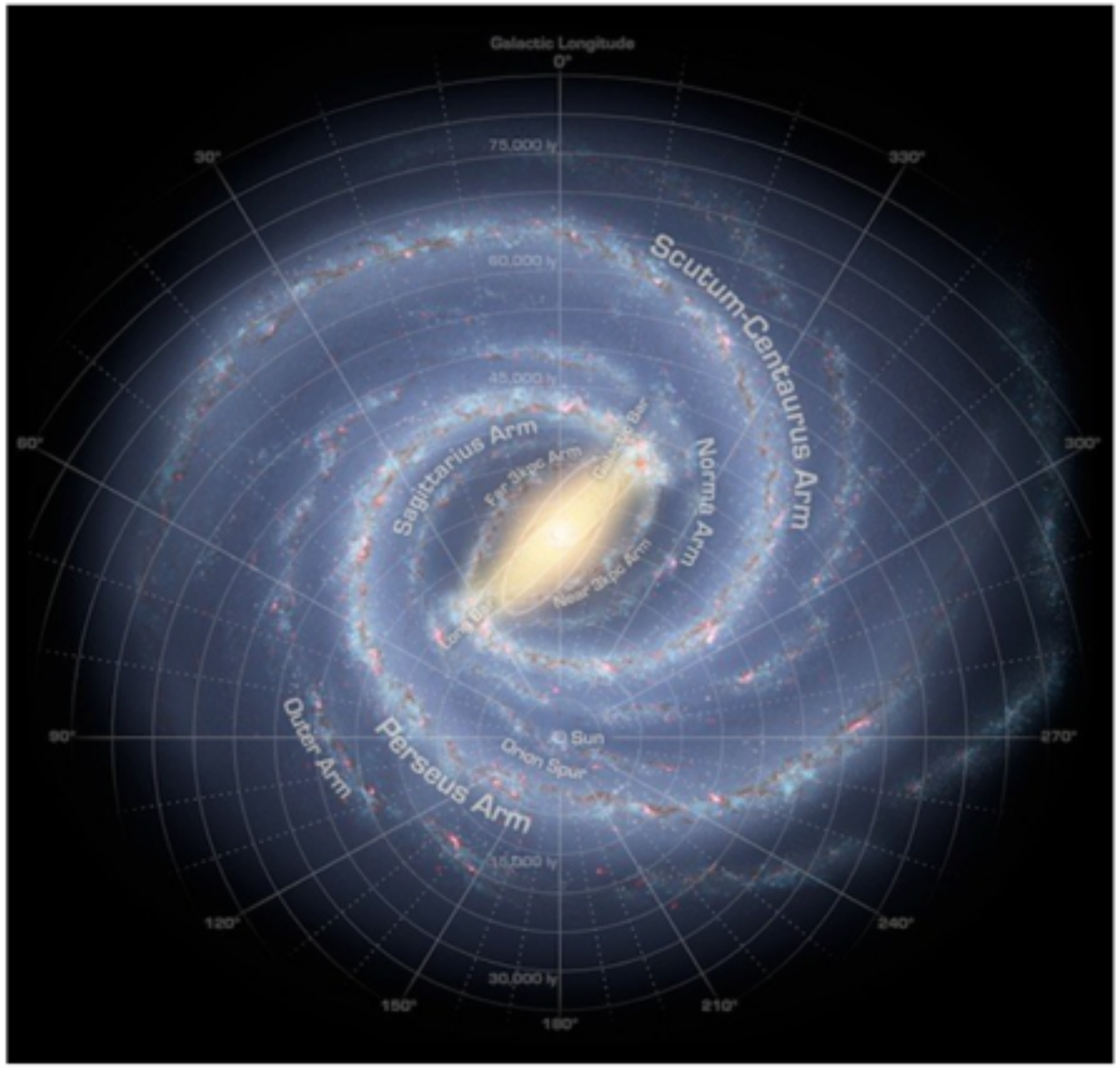
Information robust zones away from bar axes

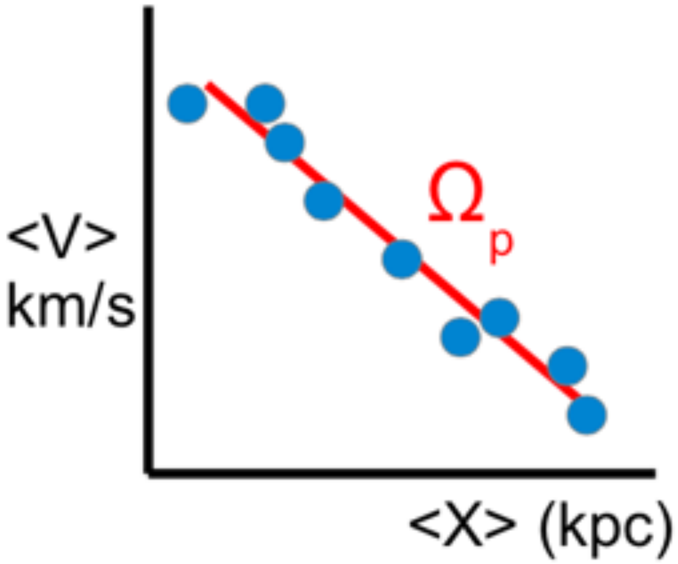


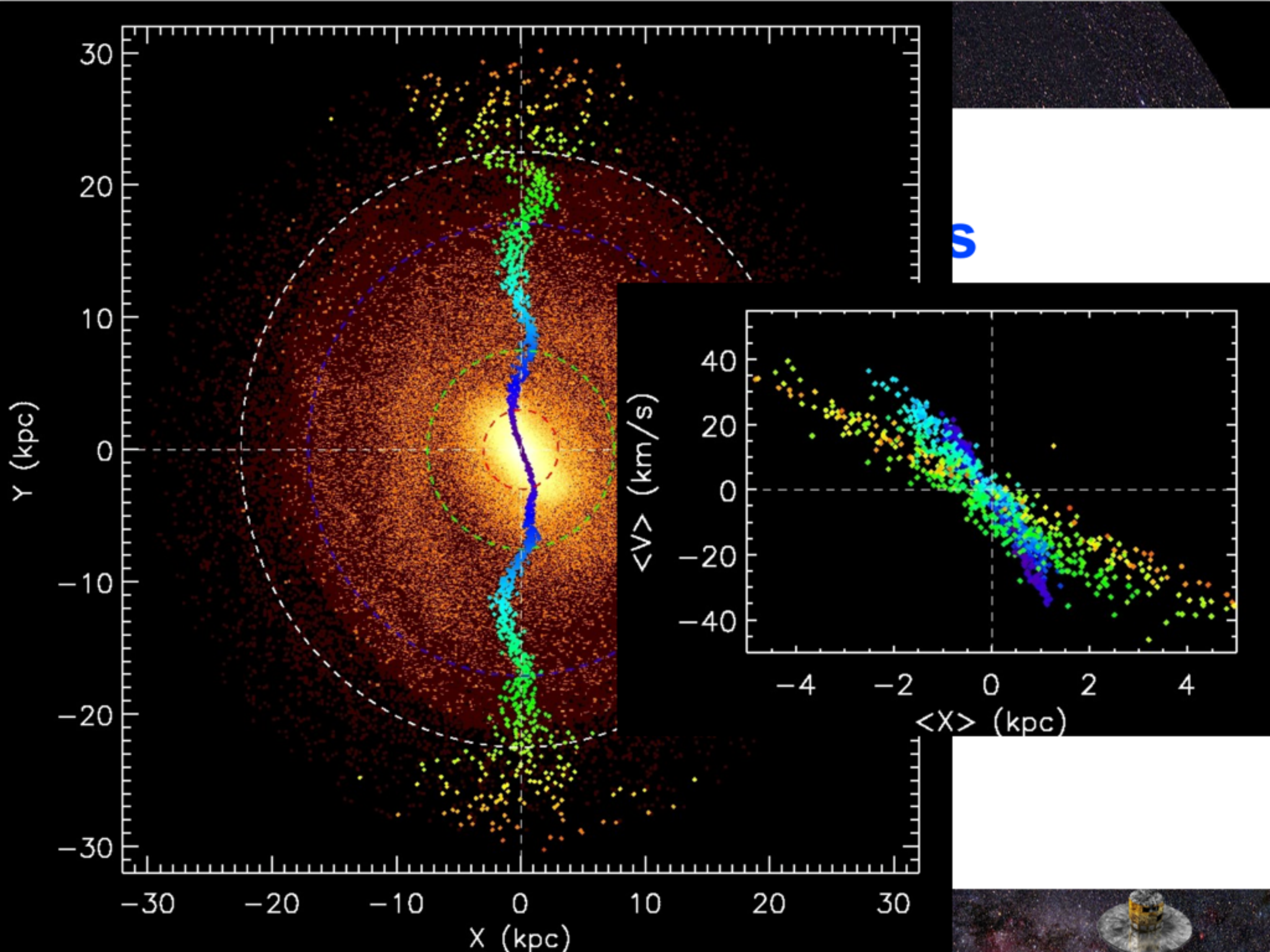
Density waves pattern speeds

Tremaine-Weinberg method (Tremaine & Weinberg 1984)

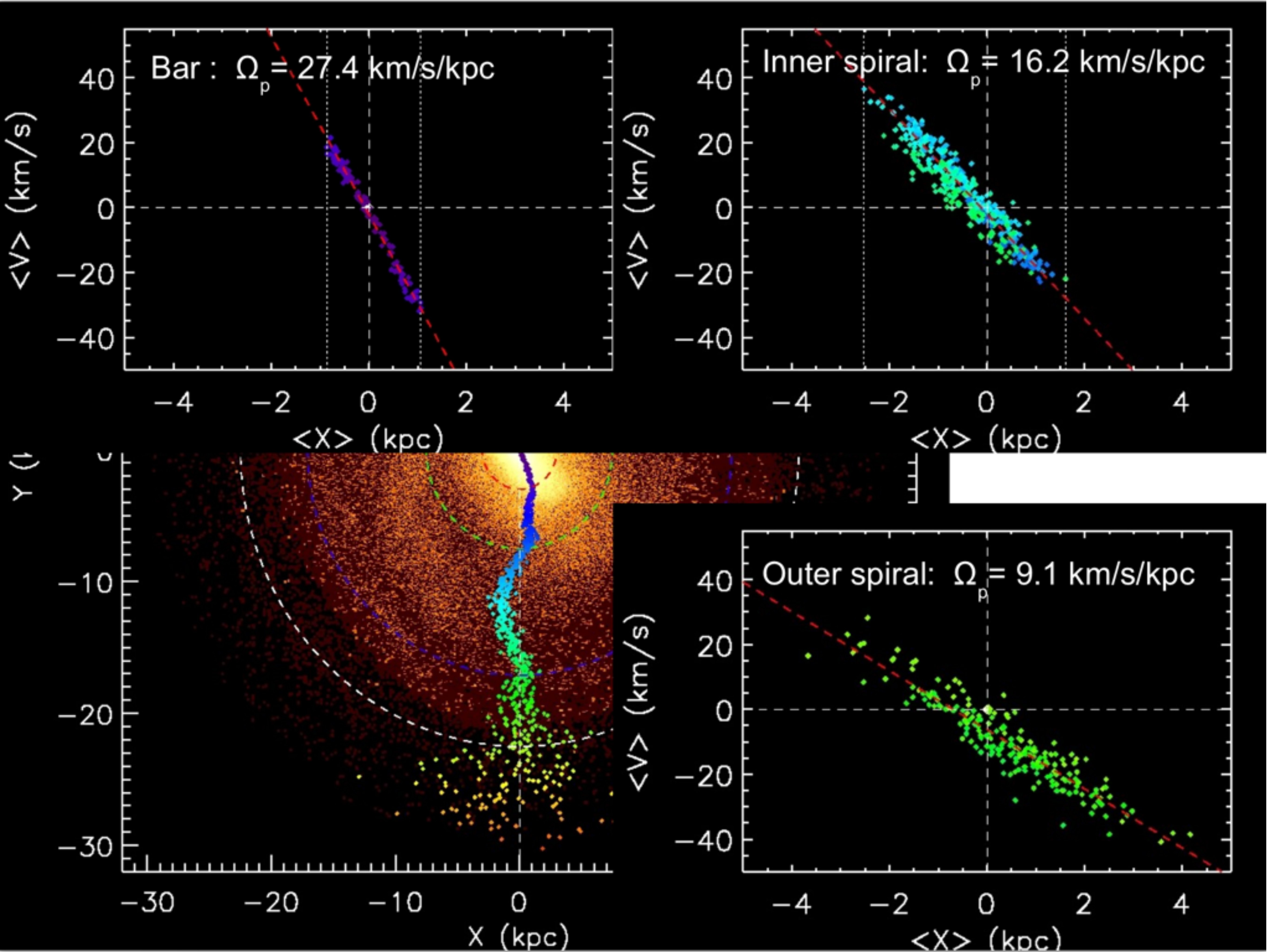
$$\Omega_p \int_{-\infty}^{\infty} \Sigma(x,y,t)\, x\, dx = \int_{-\infty}^{\infty} \Sigma(x,y,t)\, v_y(x,y,t)\, dx$$



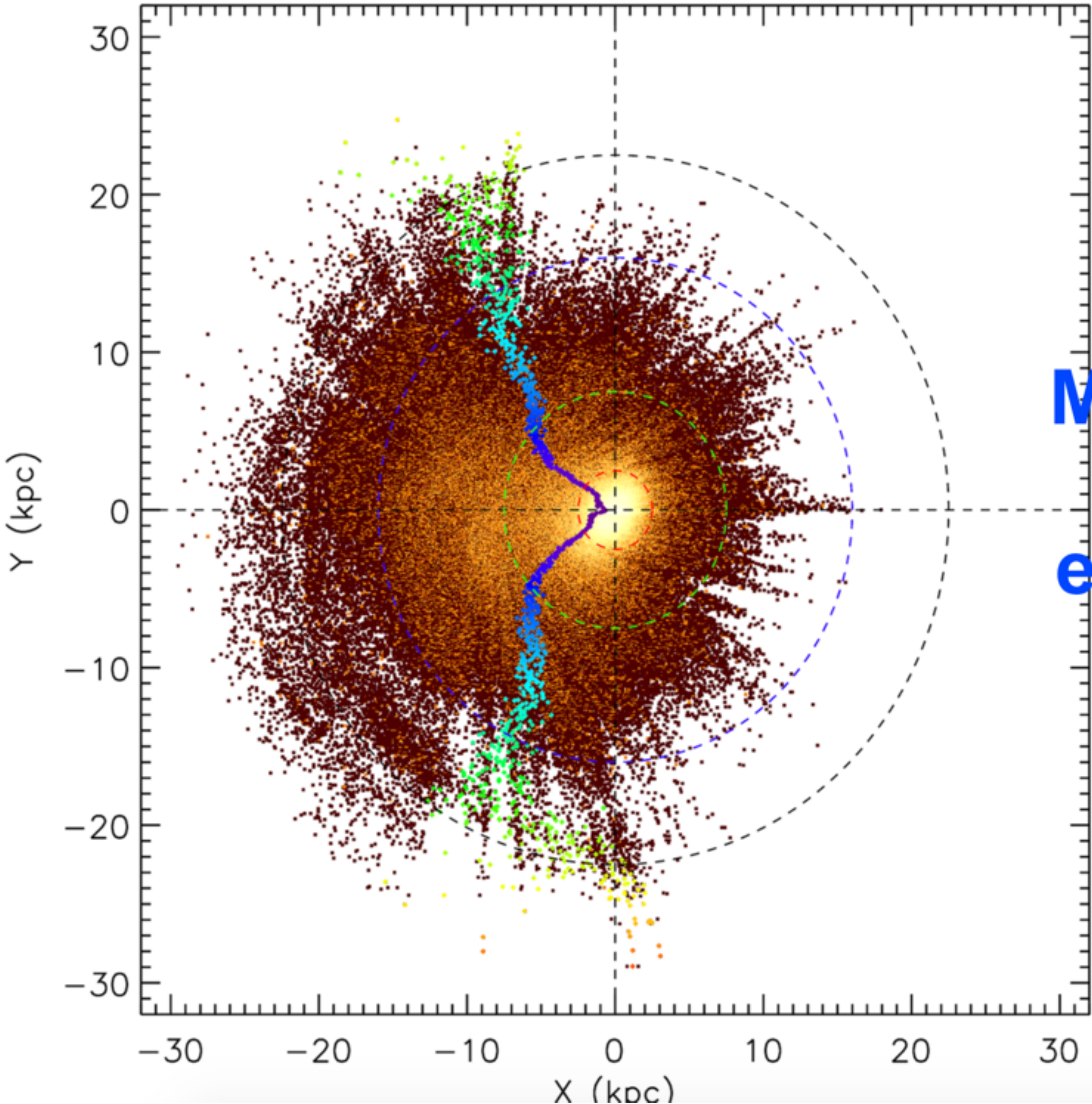




Y (kpc)
X (kpc)
<V> (km/s)
<X> (kpc)
s

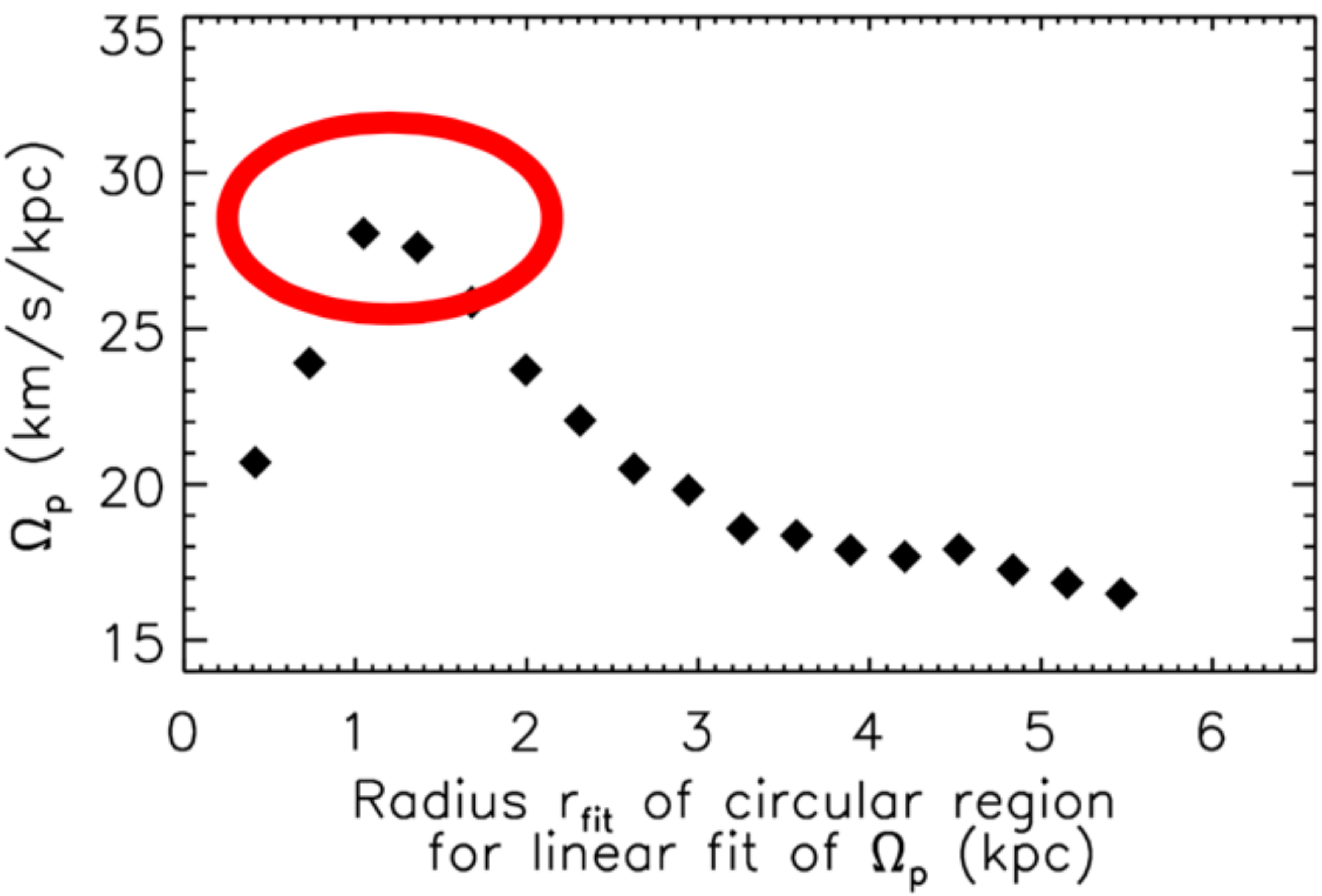


Bar : Ω_p = 27.4 km/s/kpc
Inner spiral: Ω_p = 16.2 km/s/kpc
Outer spiral: Ω_p = 9.1 km/s/kpc
<V> (km/s)
<X> (kpc)
X (kpc)

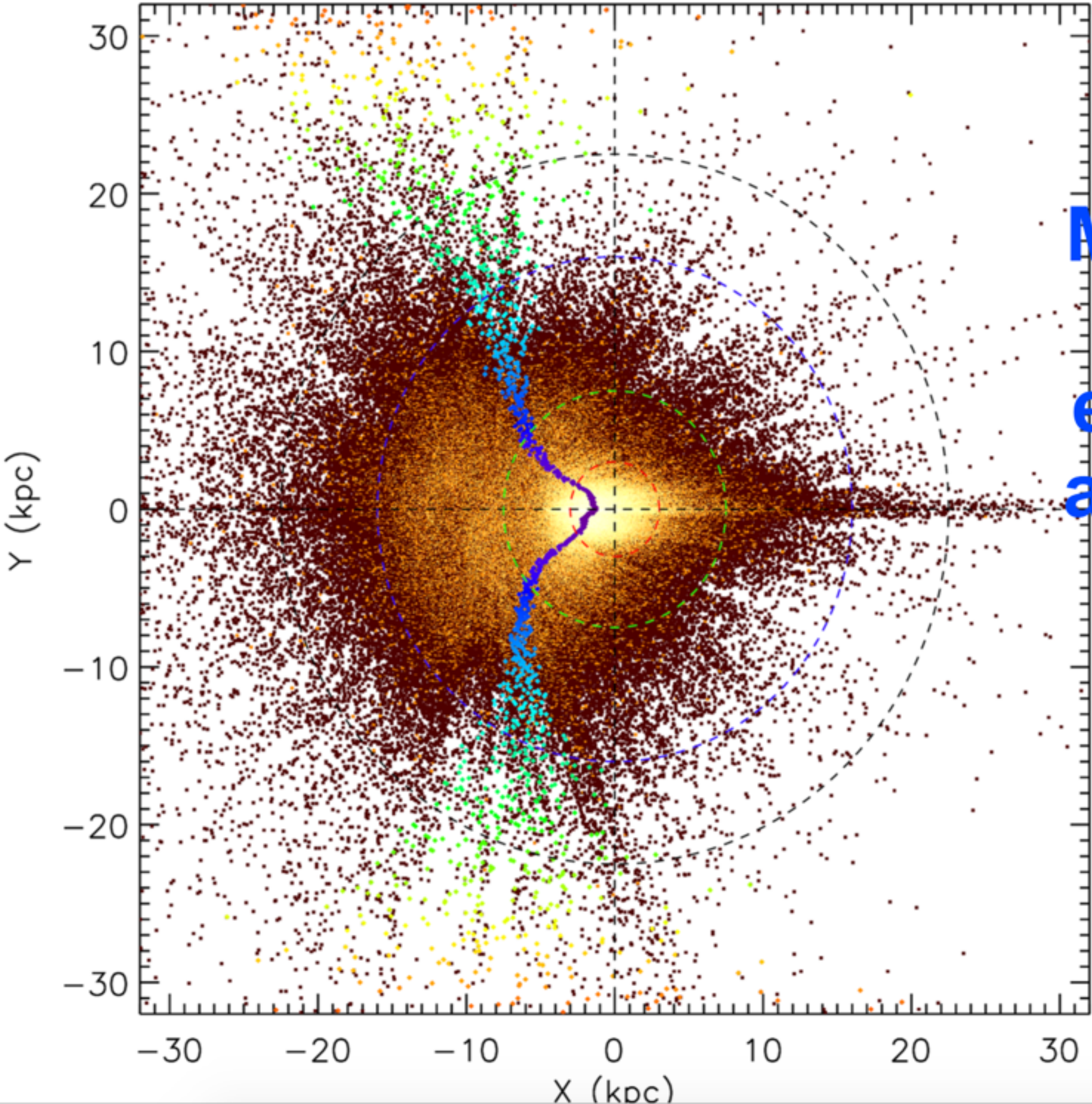


Mock data with extinction

Angular speed maximum in the bar ~ 28 km/s/kpc

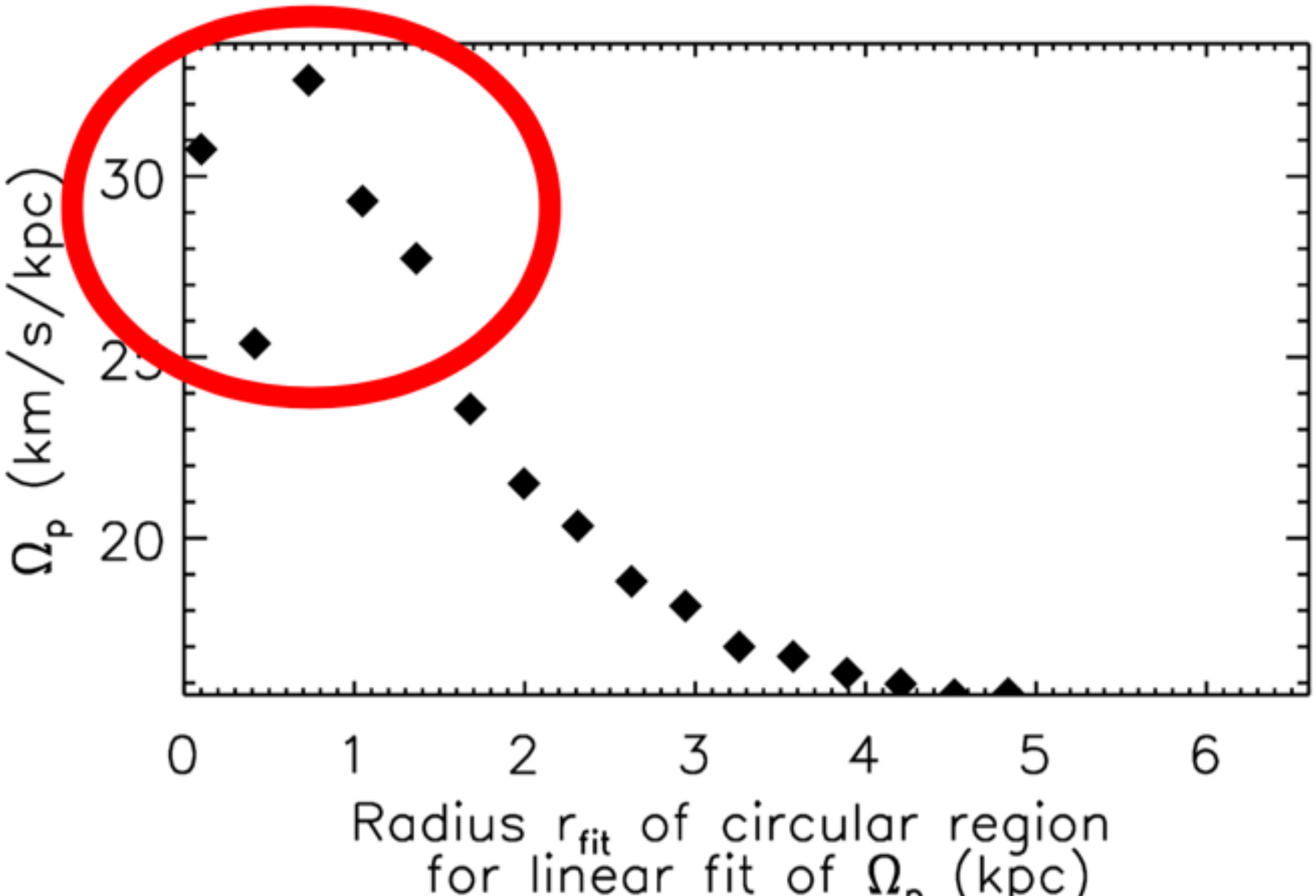


Mock data with extinction



Mock data with extinction and errors

Mock data with extinction and errors



Angular speed more scattered in the bar region

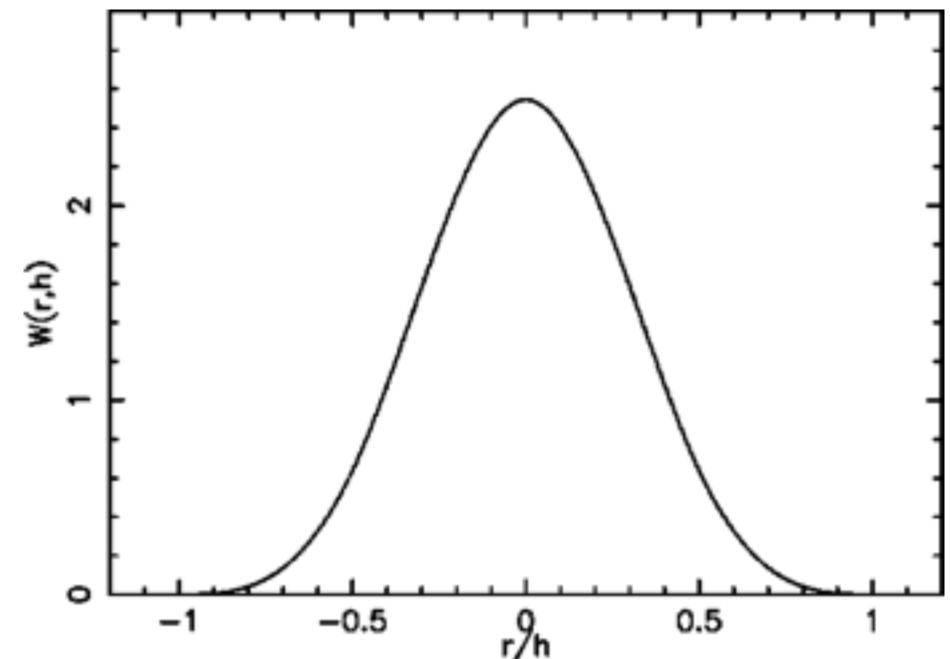
Still consistent with input value

Smoothed Particle
Local Tremaine-Weinberg method

smoothed physical value at **x**

$$< f(\mathbf{x}) >= \int f(\mathbf{x}')W(\mathbf{x}-\mathbf{x}', h)d\mathbf{x}'$$

W(r,h): smoothing kernel,
h: smoothing length



spline kernel r=|**x**-**x’**|,

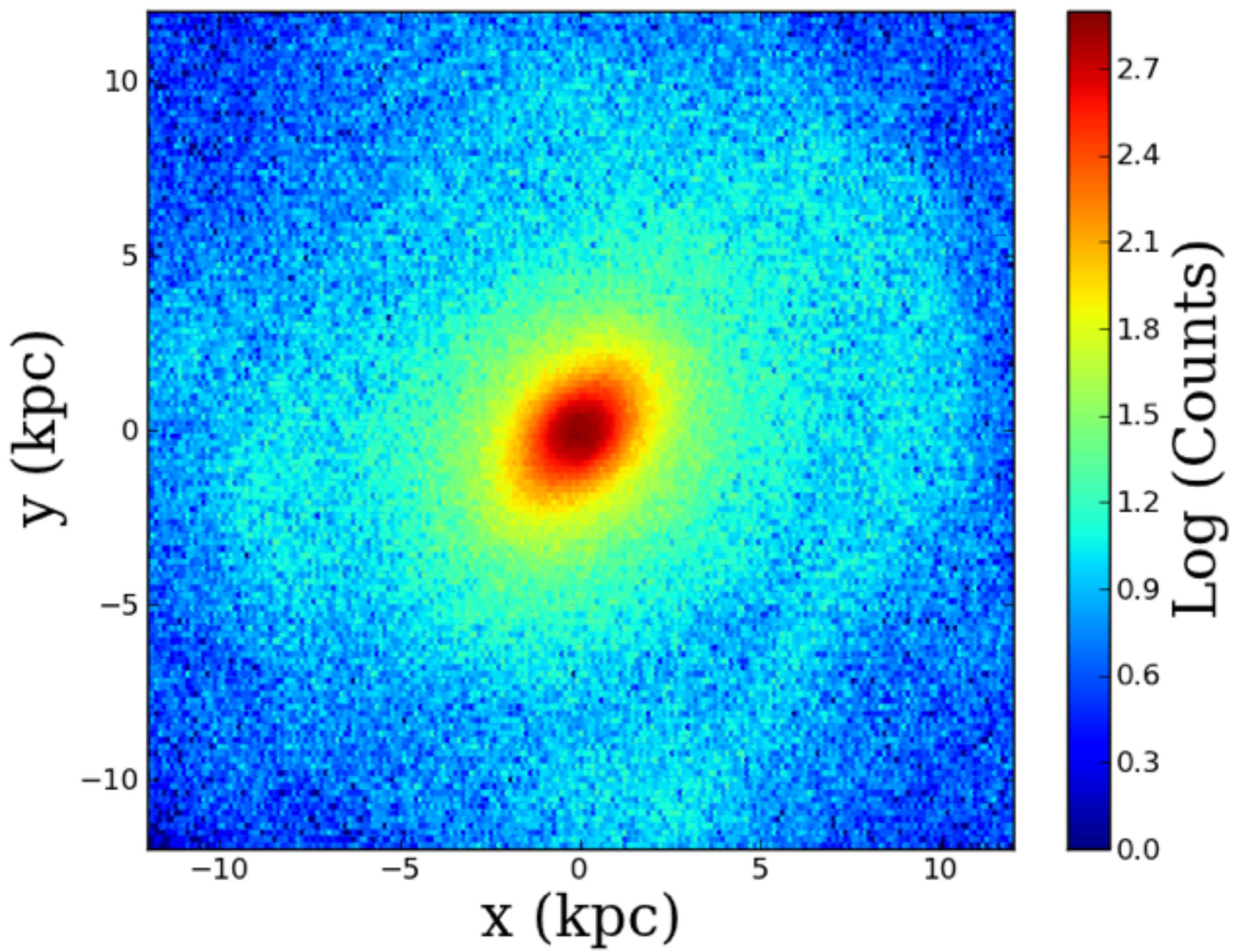
$$W(r,h) = \frac{8}{\pi h^3}\begin{cases} 1-6(r/h)^2+6(r/h)^3 & \text{if } 0 \le r/h \le 1/2, \\ 2[1-(r/h)]^3 & \text{if } 1/2 \le r/h \le 1, \\ 0 & \text{otherwise.} \end{cases}$$

derivatives

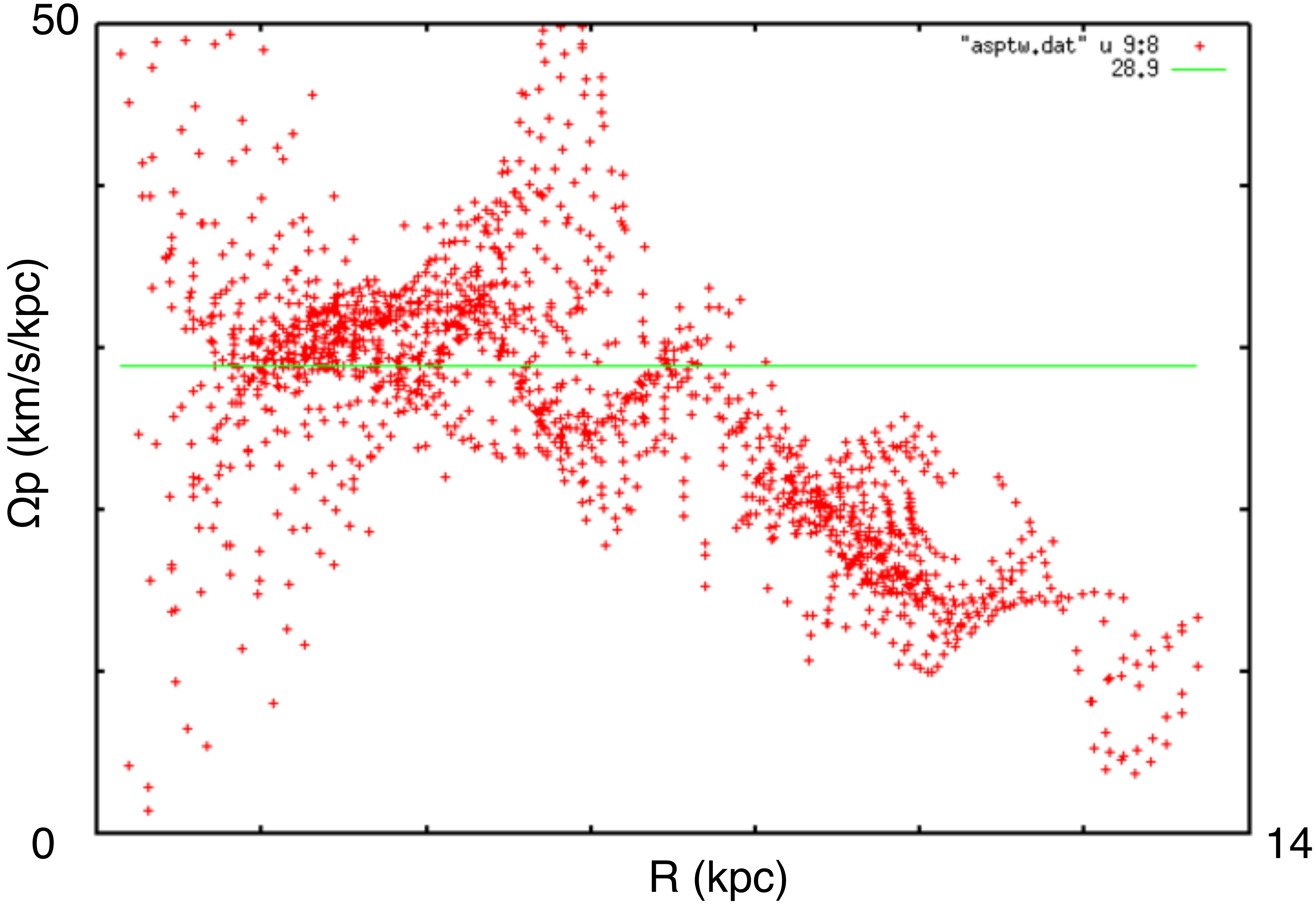
$$< \nabla f(\mathbf{x}) >= \sum_j \frac{m_j}{\rho_j} f(\mathbf{x}_j)\nabla_i W(\mathbf{x}-\mathbf{x}_j, h)$$

$$\frac{\partial}{\partial x}\left[\Sigma(x,y,t)v_x(x,y,t)\right] + \frac{\partial}{\partial y}\left[\Sigma(x,y,t)v_y(x,y,t)\right] = \Omega_p\left(y\frac{\partial\Sigma}{\partial x} - x\frac{\partial\Sigma}{\partial y}\right)$$

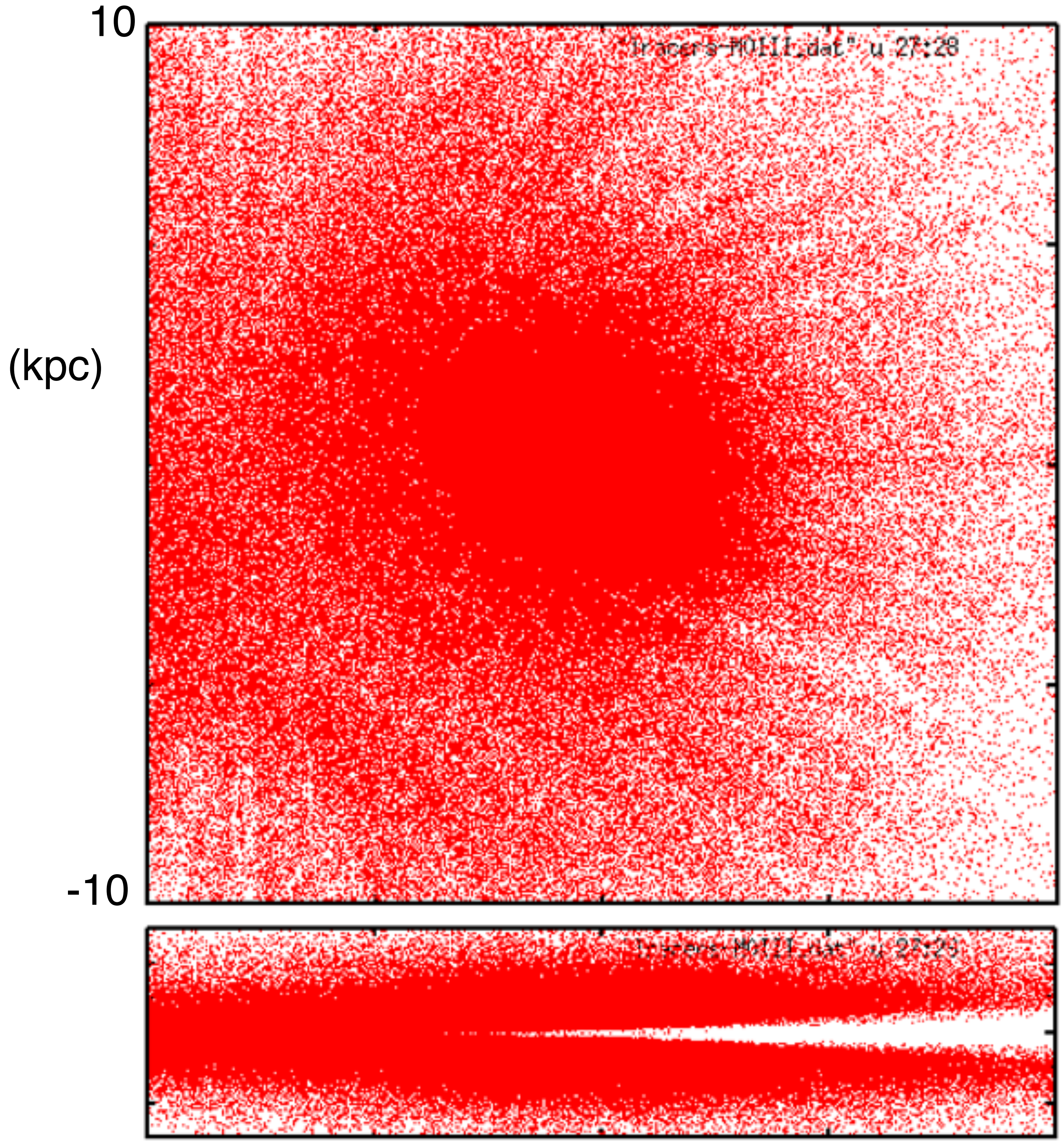
Mock data: GD3 (Jason Hunt)
N-body barred disc spanshot



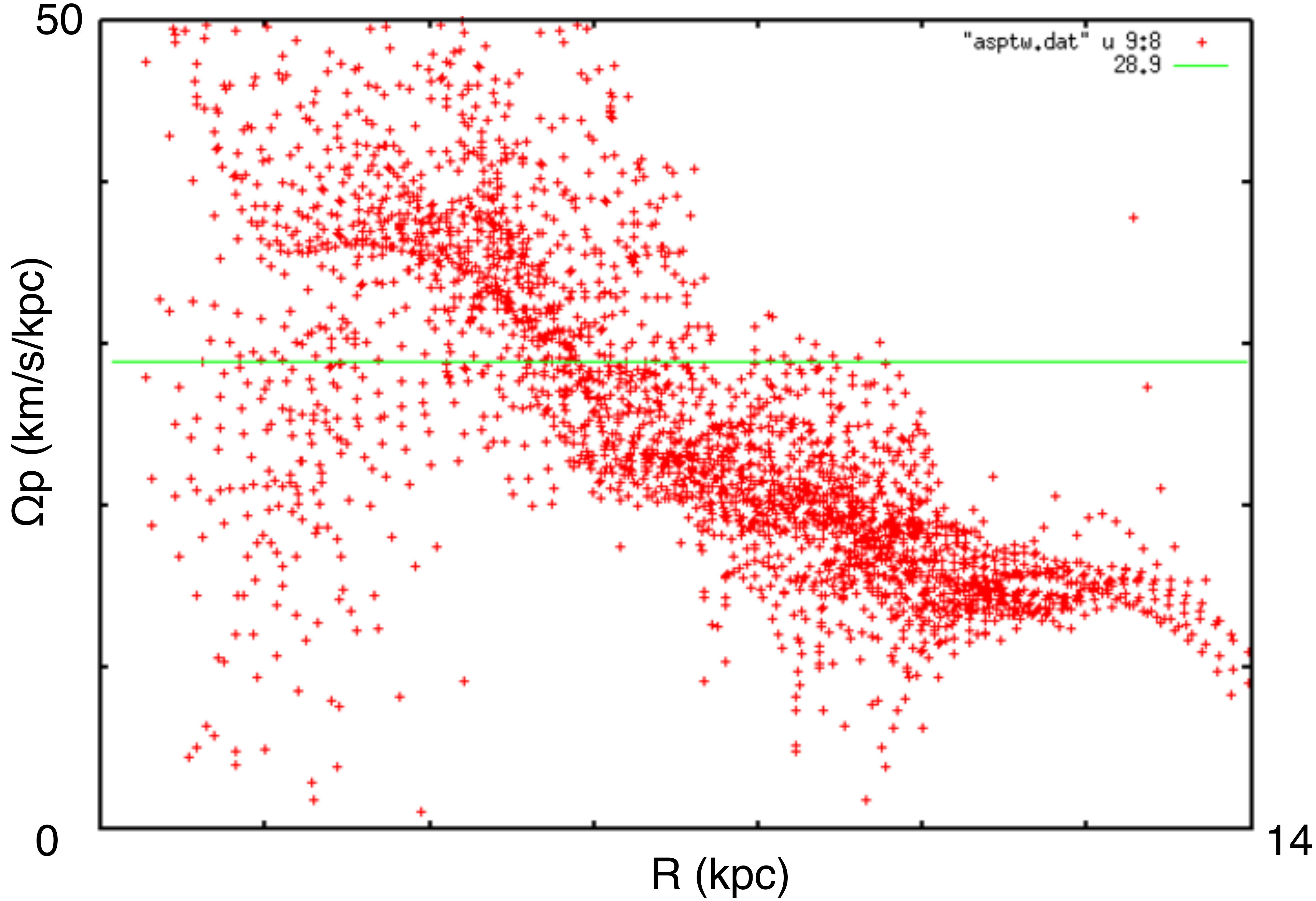
Smoothed Particle
Local Tremaine-Weinberg method: all data



GD3 M0III tracers

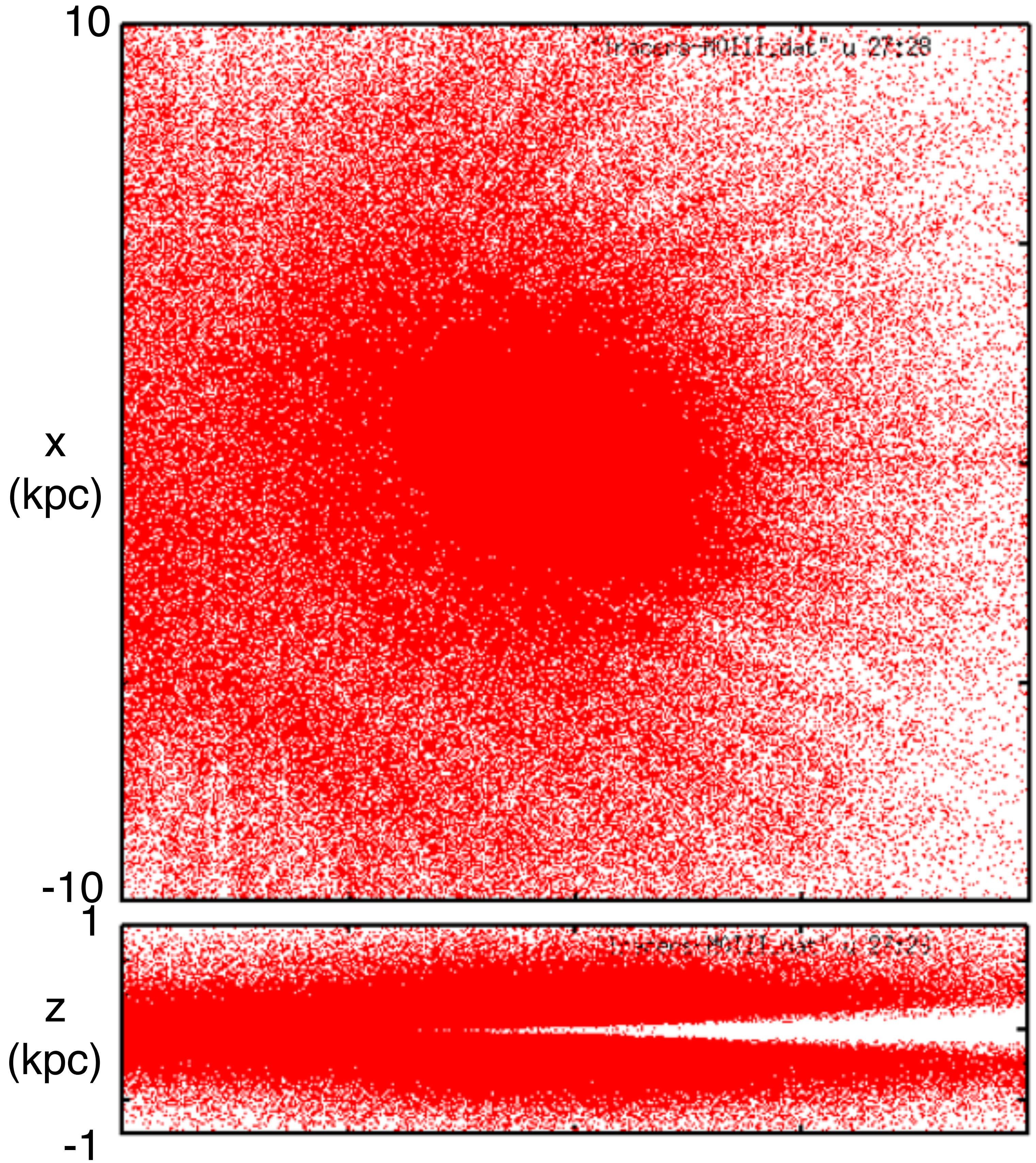


Smoothed Particle
Local Tremaine-Weinberg method: M0III tracers

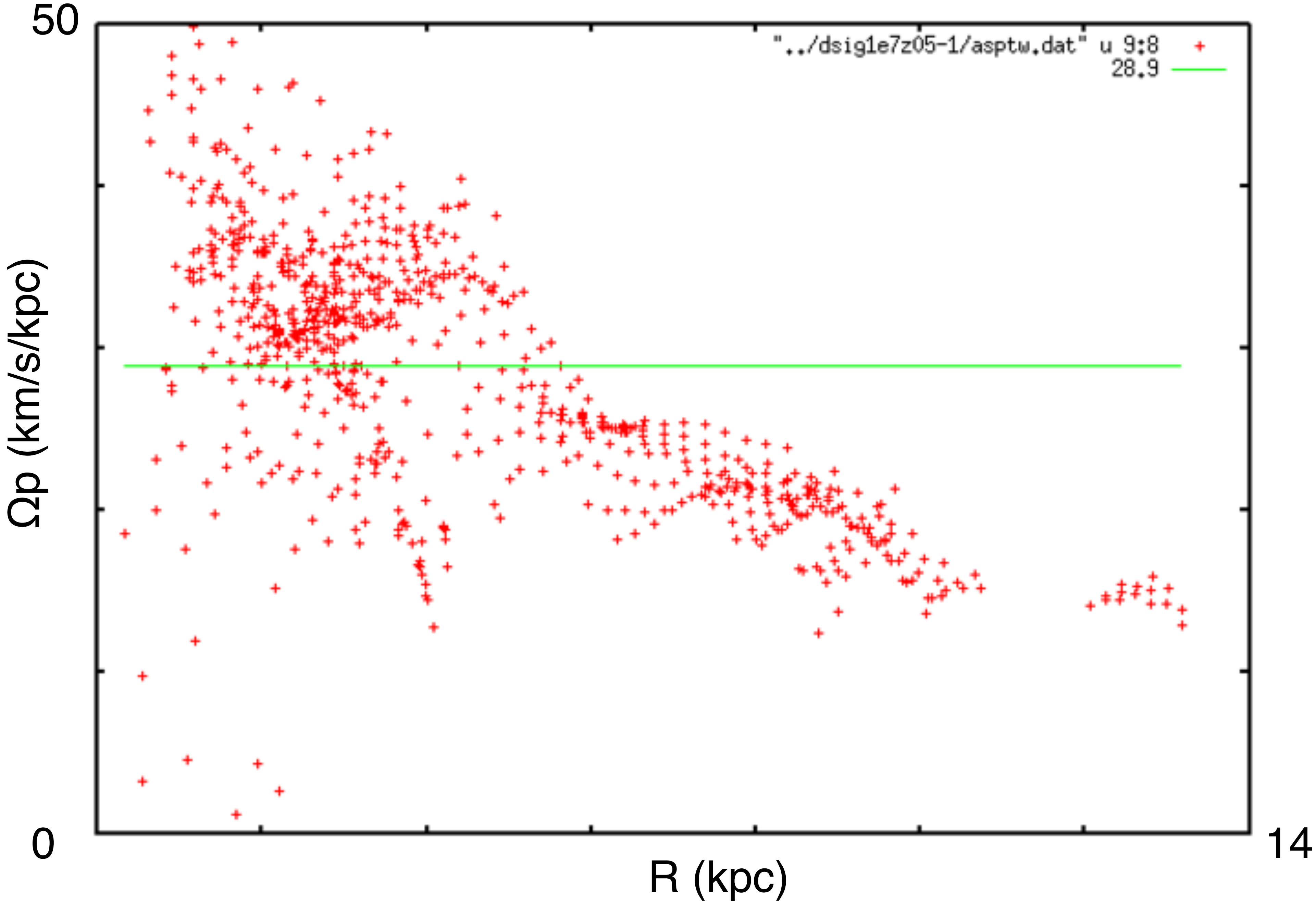


Over estimate the pattern speed

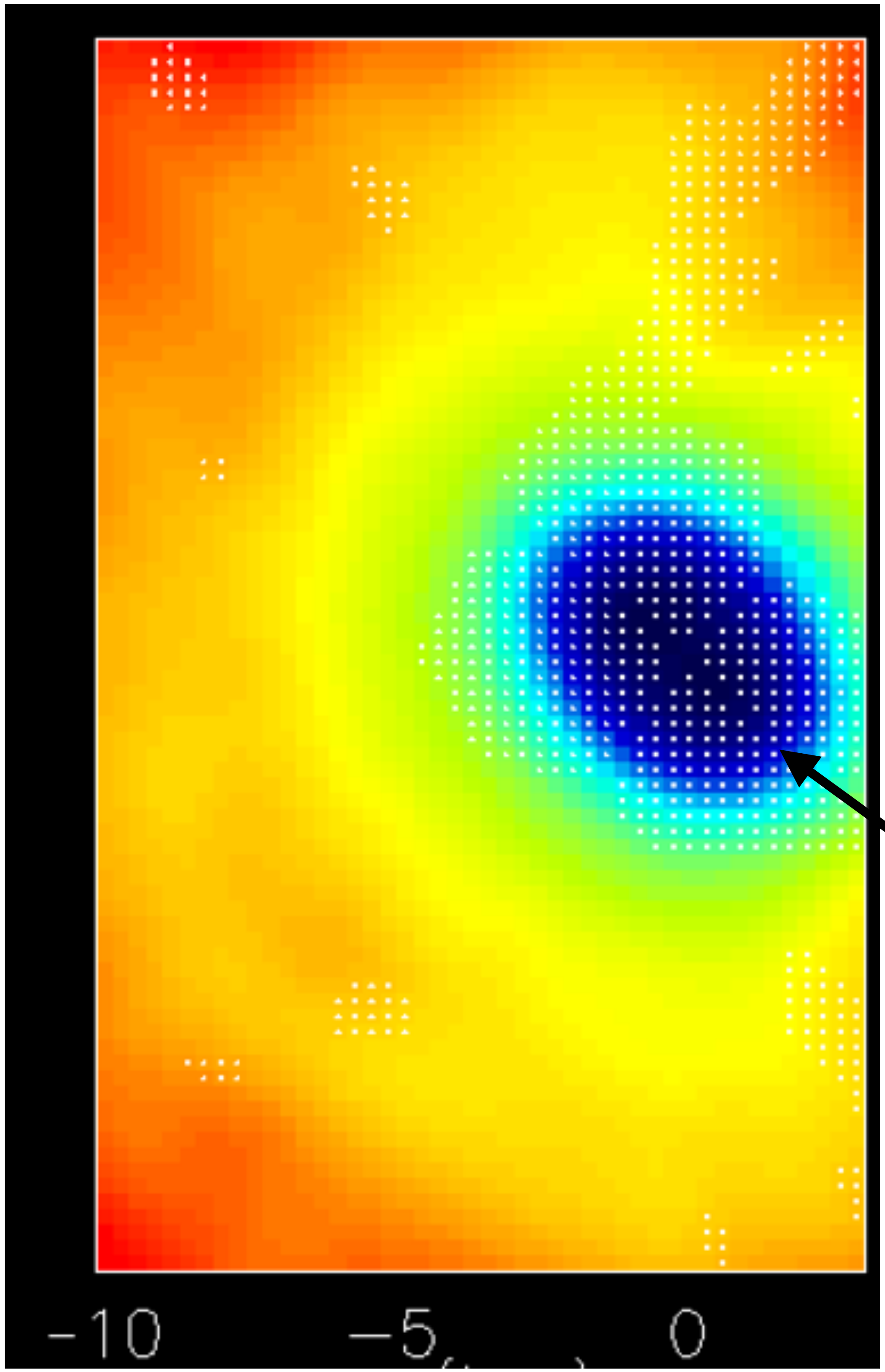
GD3 M0III tracers



Smoothed Particle
Local Tremaine-Weinberg method: 0.5<|z|<1 kpc



TW method useful for identifying the bar position?



$$\frac{\partial}{\partial x}\left[\Sigma(x,y,t)v_x(x,y,t)\right] + \frac{\partial}{\partial y}\left[\Sigma(x,y,t)v_y(x,y,t)\right] = \Omega_p\left(y\frac{\partial \Sigma}{\partial x} - x\frac{\partial \Sigma}{\partial y}\right)$$

$\left(y\frac{\partial \Sigma}{\partial x} - x\frac{\partial \Sigma}{\partial y}\right)$ is small.

Scrutinising the nature of spiral arms

Observational signatures in stellar kinematics

Rob Grand, Hoda Abedi, Victor Debattista, Francesca Figueras

Jason Hunt, Lucie Jilkova, Daisuke Kawata

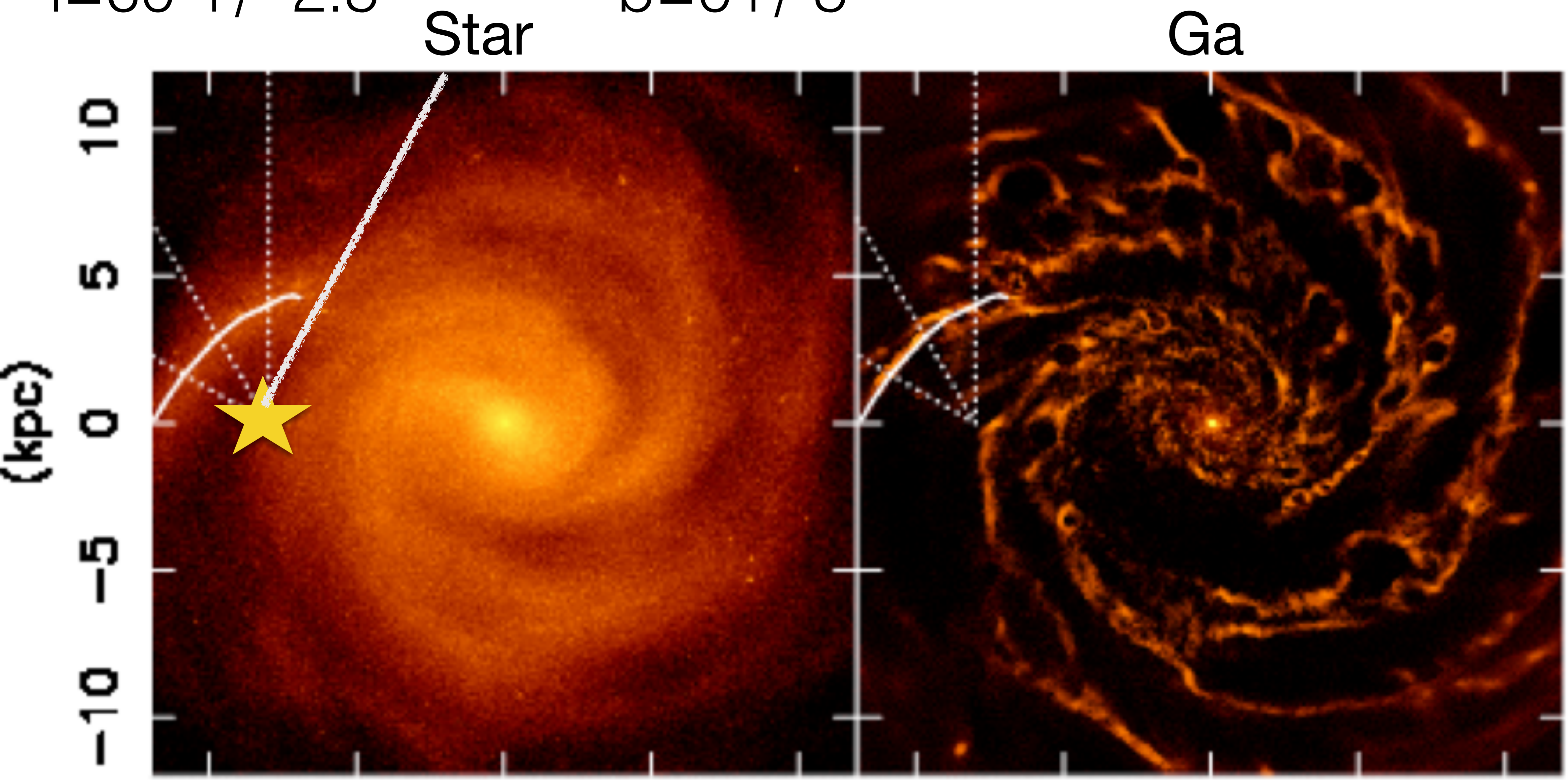
Carmen Martinez-Barbosa, Santi Roca-Fabrega,

Mock data suite

- Kawata et al. 2014 - **Co-rotating spiral arms, N-body**
- Debattista 2014 - **Grand design N-body model**
- Roca-Fabrega et al 2014 - **Imposed TWA density waves (unbarred), test particles**
- Roca-Fabrega et al 2014 - **Strong bar N-body (manifolds)**

N-body model, **co-rotating** spiral arms
(Kawata et al. 2014)

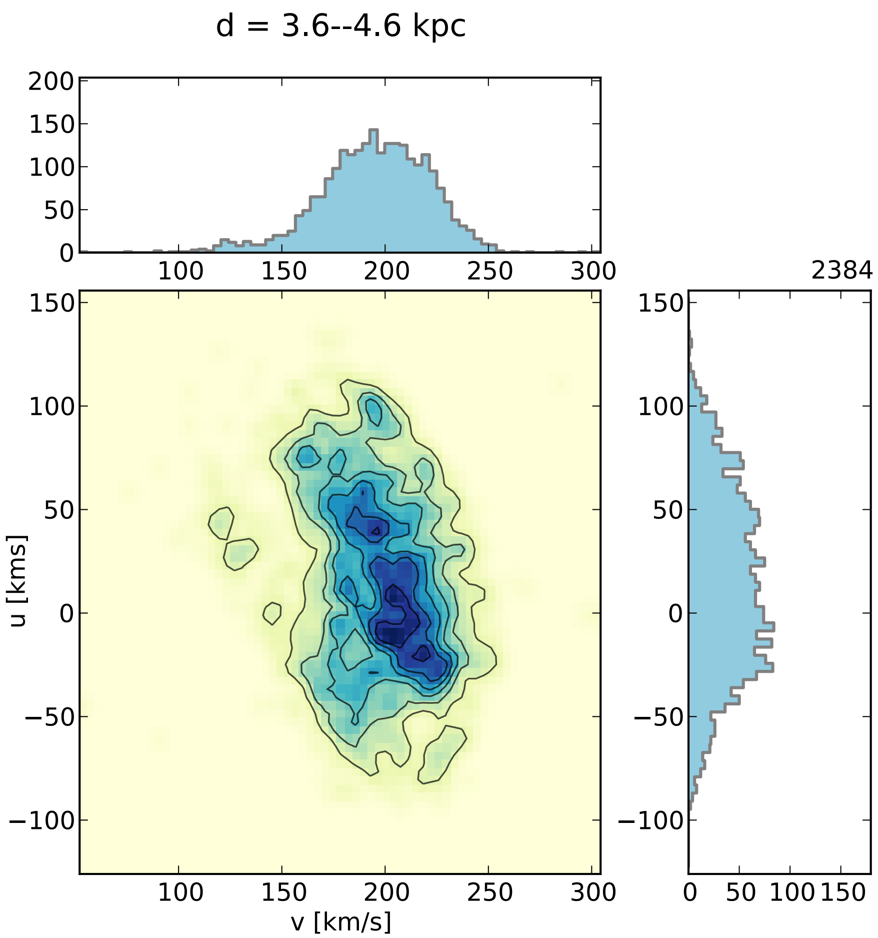
l=60 +/- 2.5 b=0+/-5



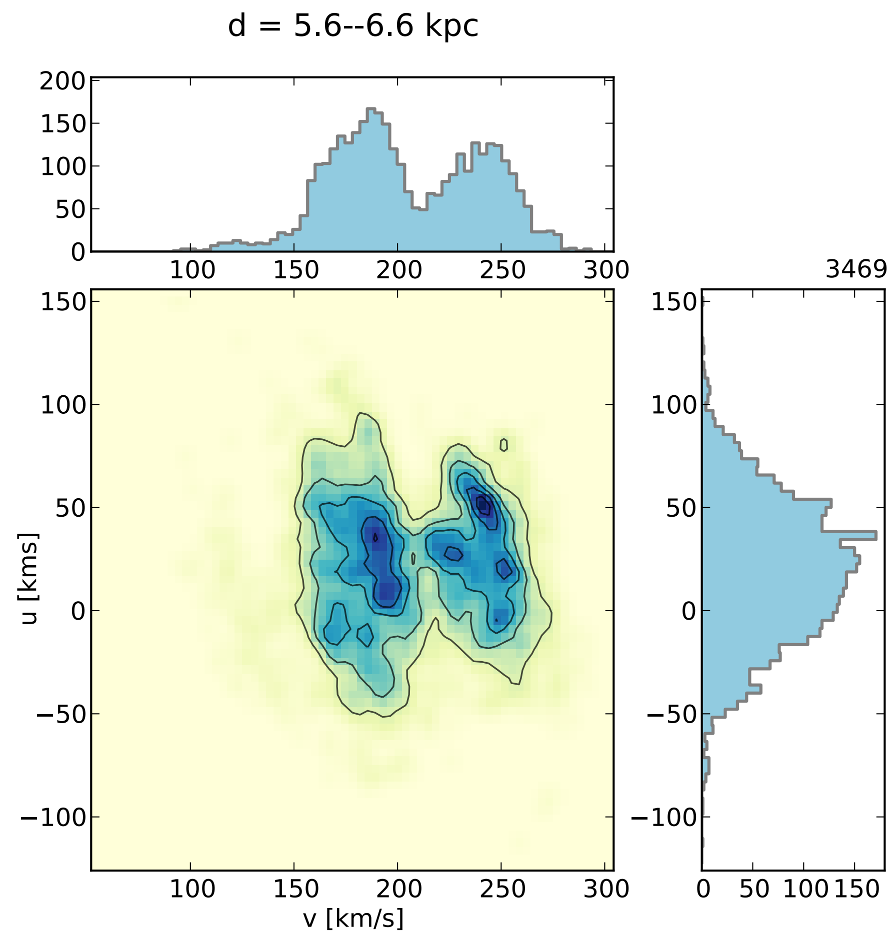
Bin in heliocentric distance —> get kinematics in each bin

N-body model, **co-rotating** spiral arms
(Kawata et al. 2014)

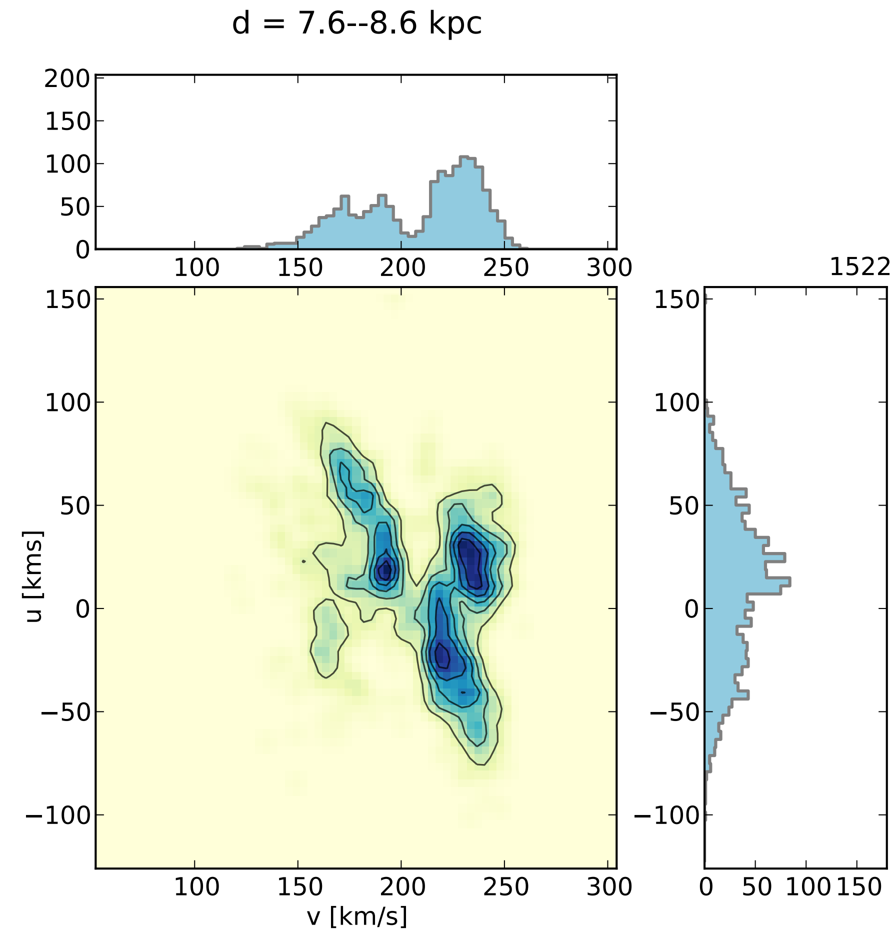
behind



in the spiral



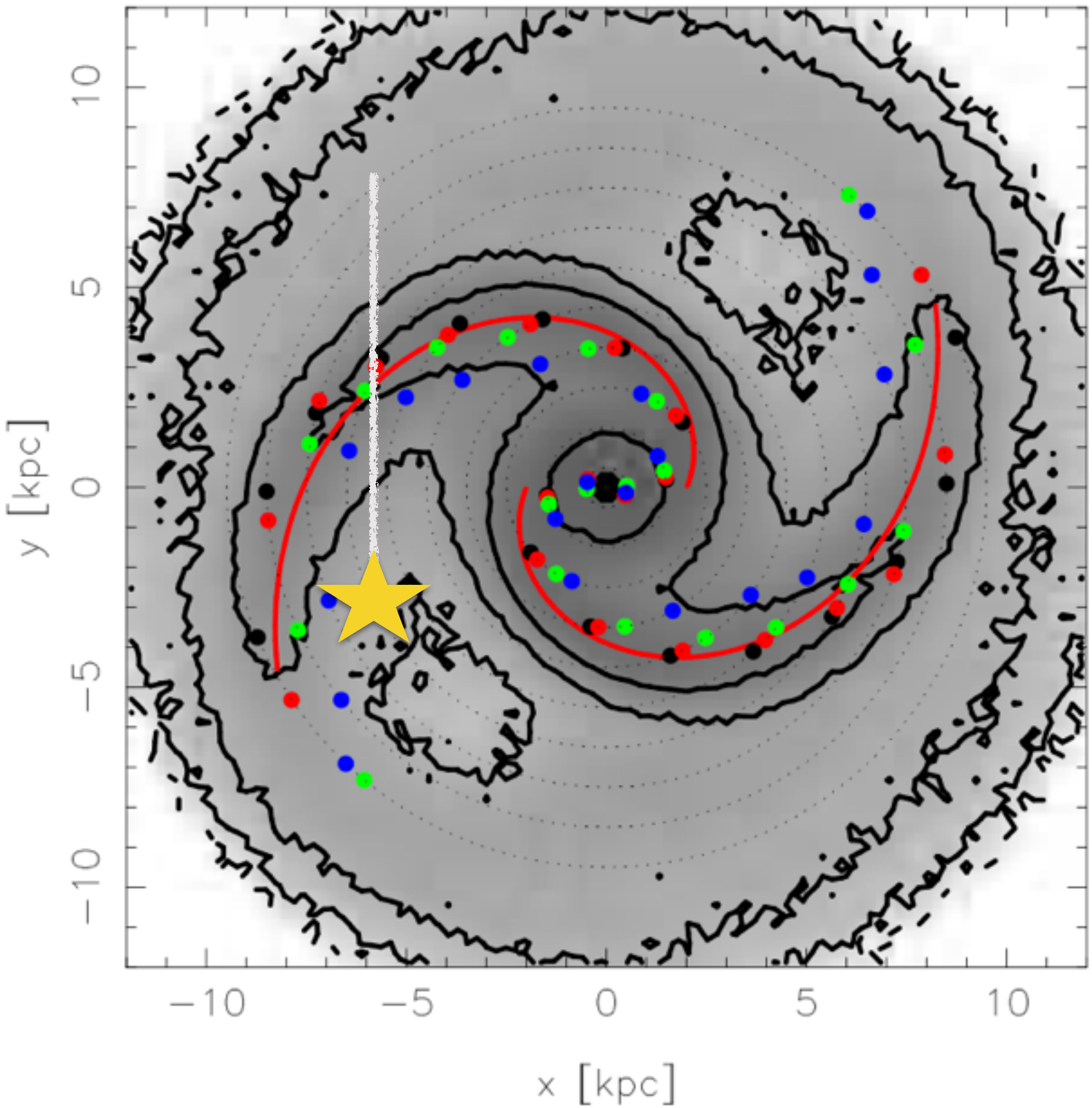
in front



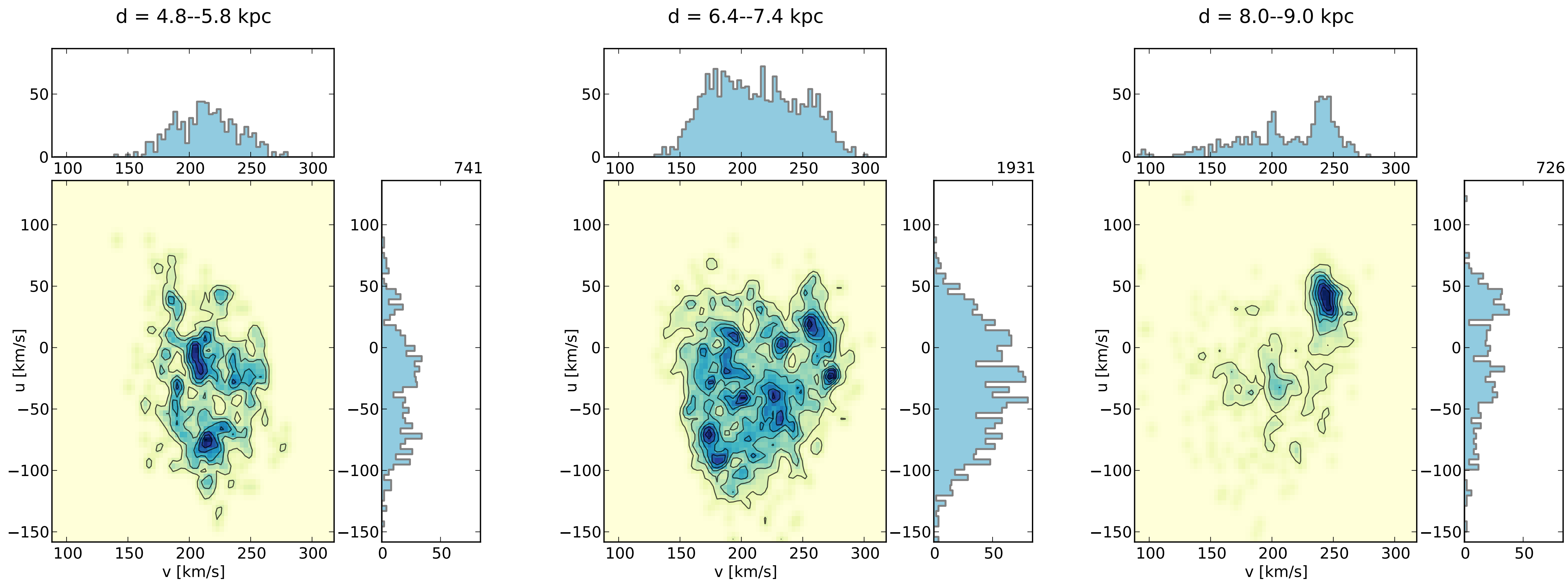
u=radial velocity
v=rotational velocity

plots courtesy of Lucie Jilkova!!!

N-body model from Debattista 2014

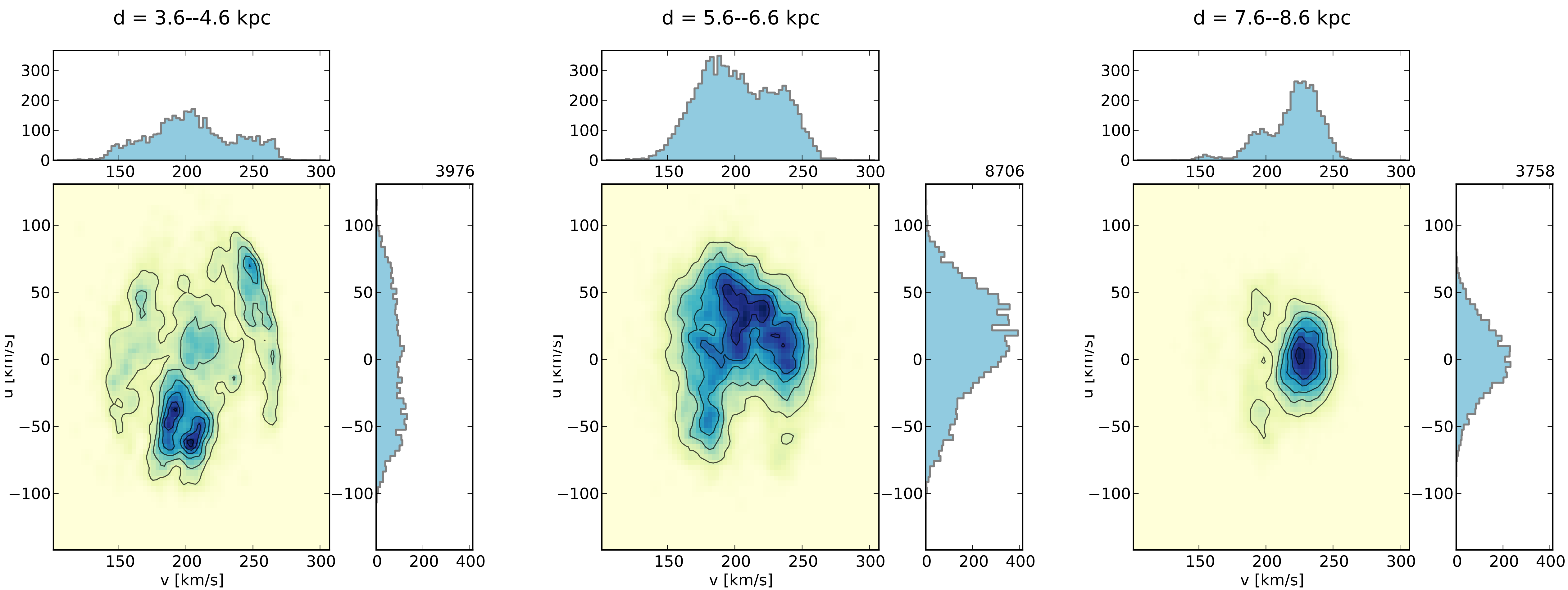


N-body model from Debattista 2014



behind　　in the spiral　　in front

Test particle, **density waves** (Roca-Fabrega et al.)

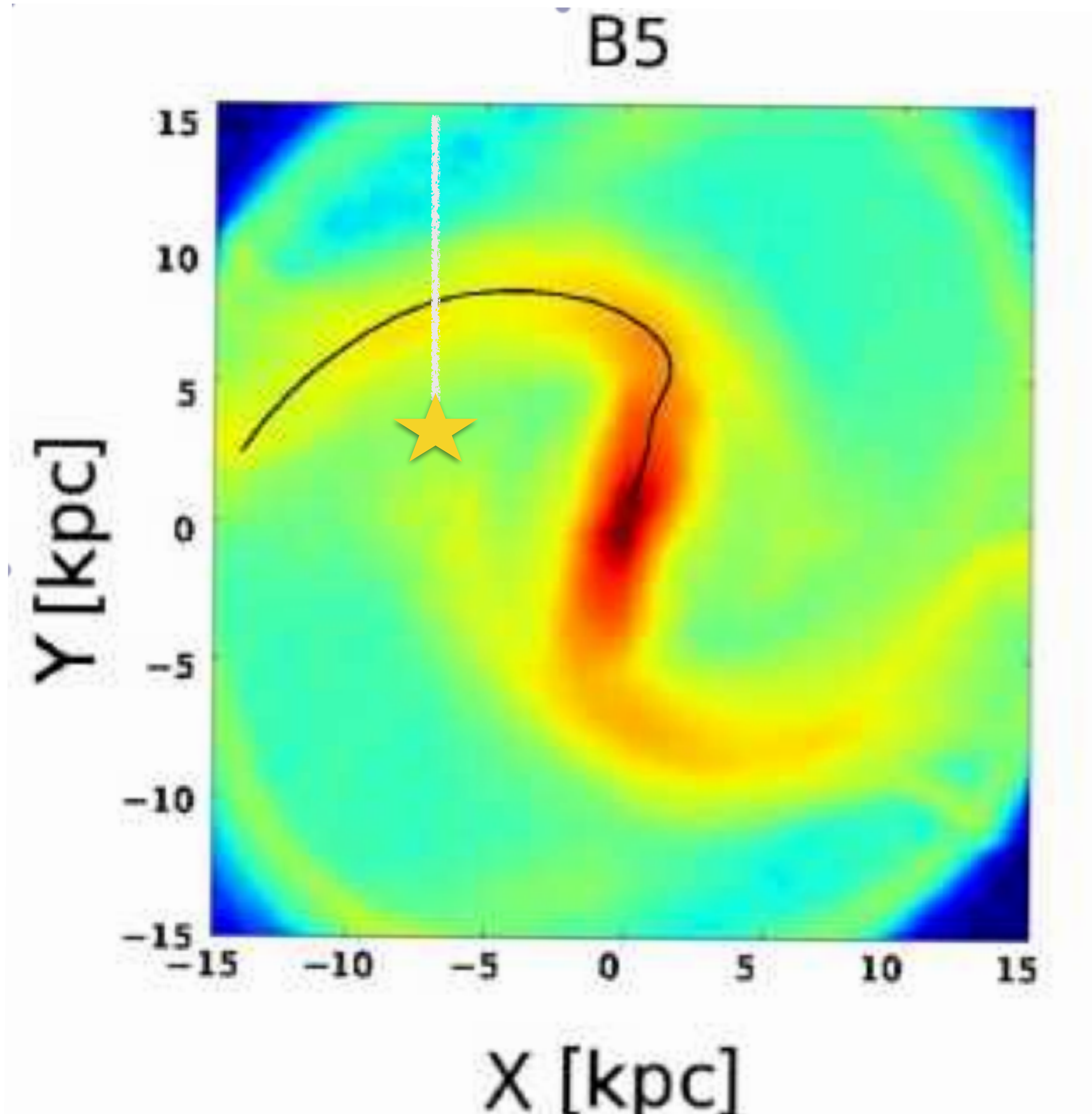


behind

in the spiral

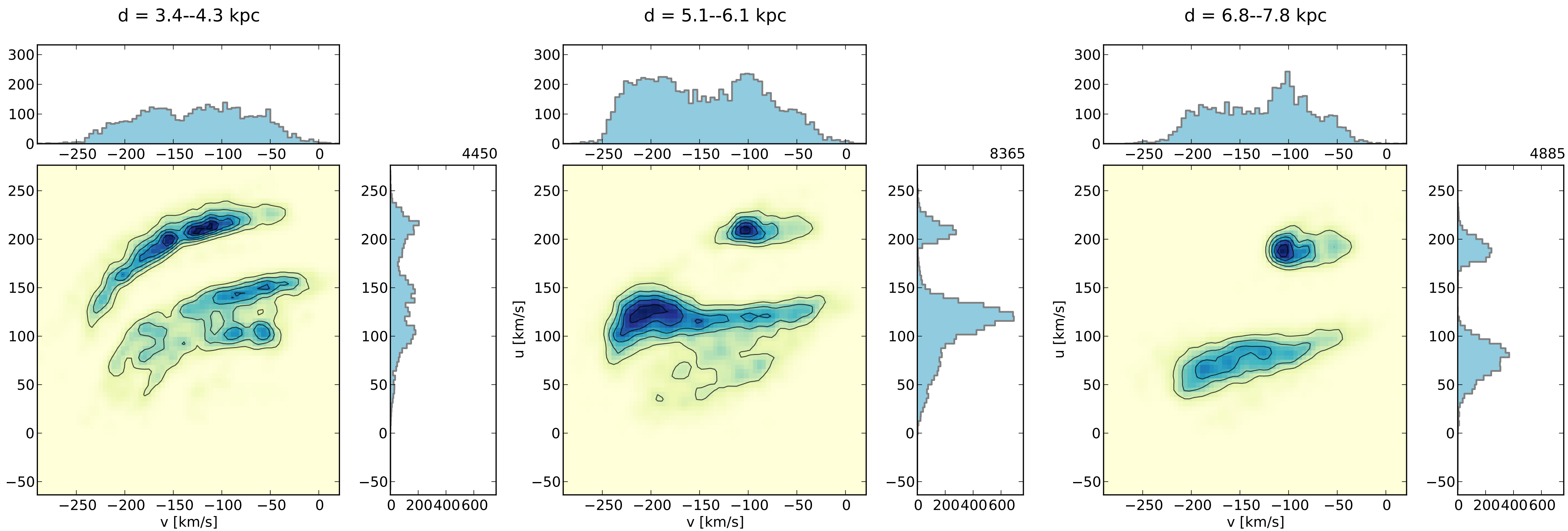
in front

N-body, strong bar, **manifolds** (Roca-Fabrega et al. 2014)



N-body, strong bar, **manifolds** (Roca-Fabrega et al. 2014)

N-body data

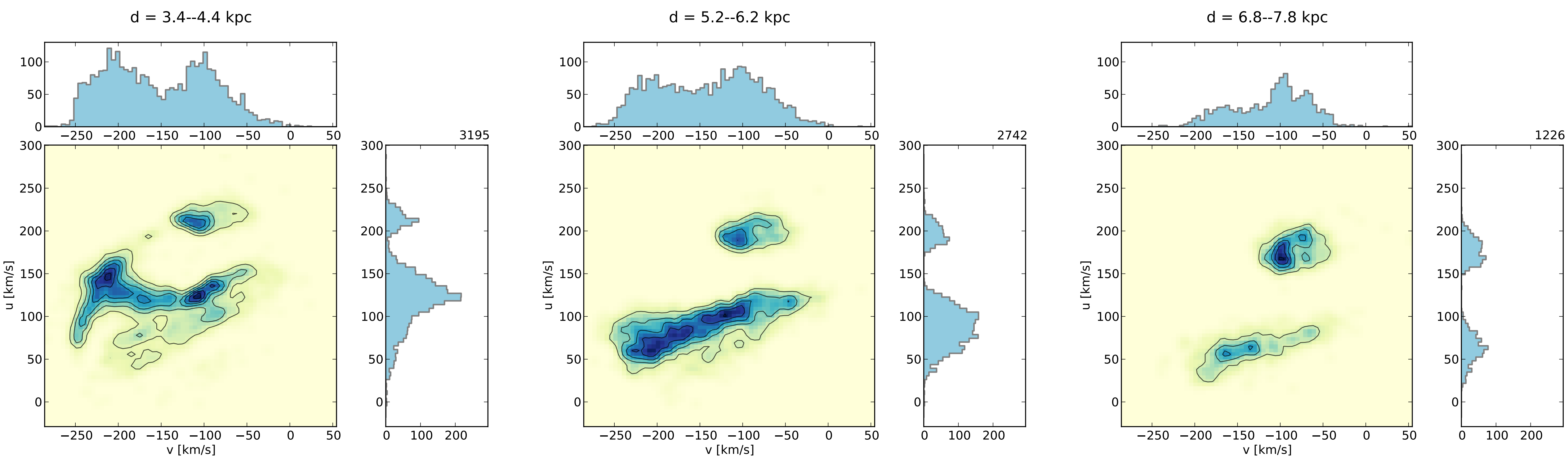


behind

in the spiral

in front

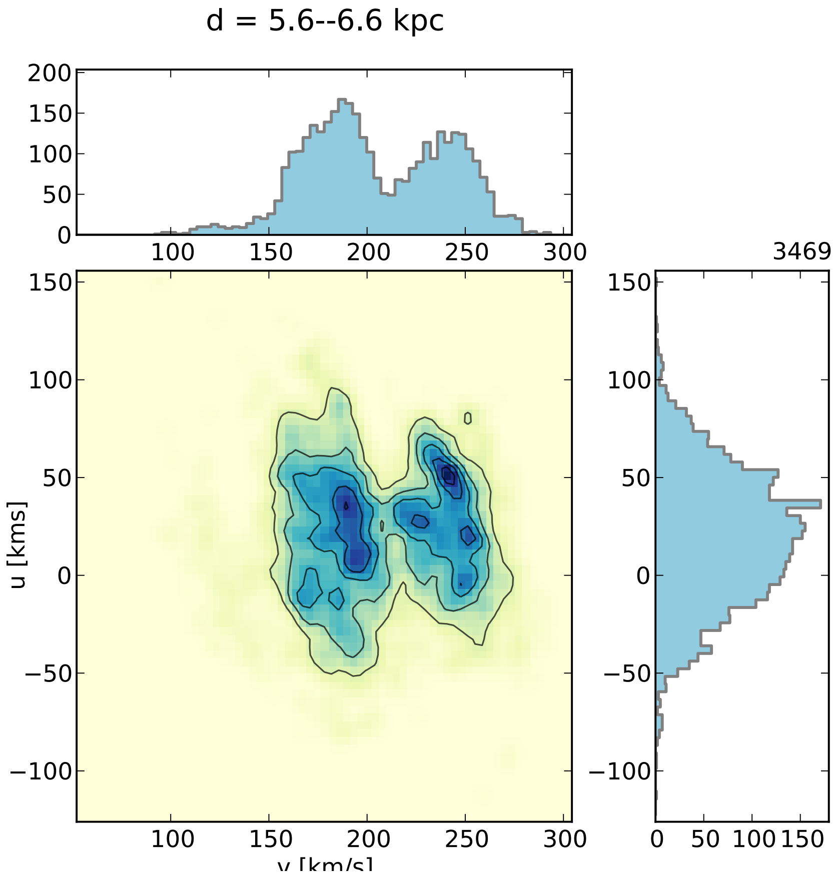
Extinction, errors

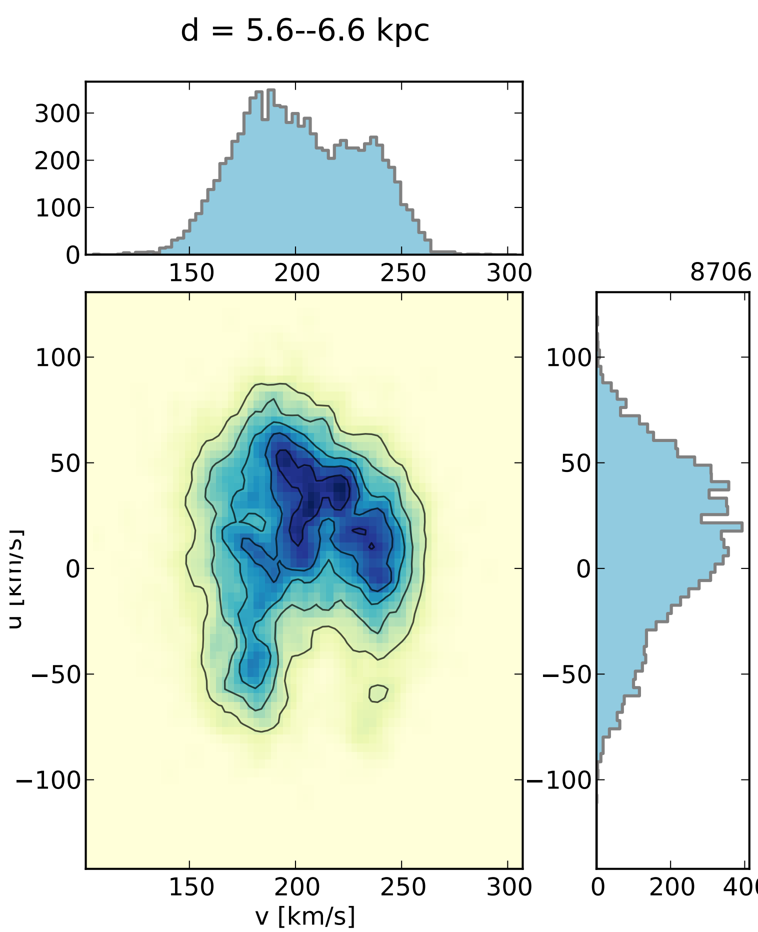


SNAPDRAGONS (Hunt, Kawata, Grand et al. in prep)

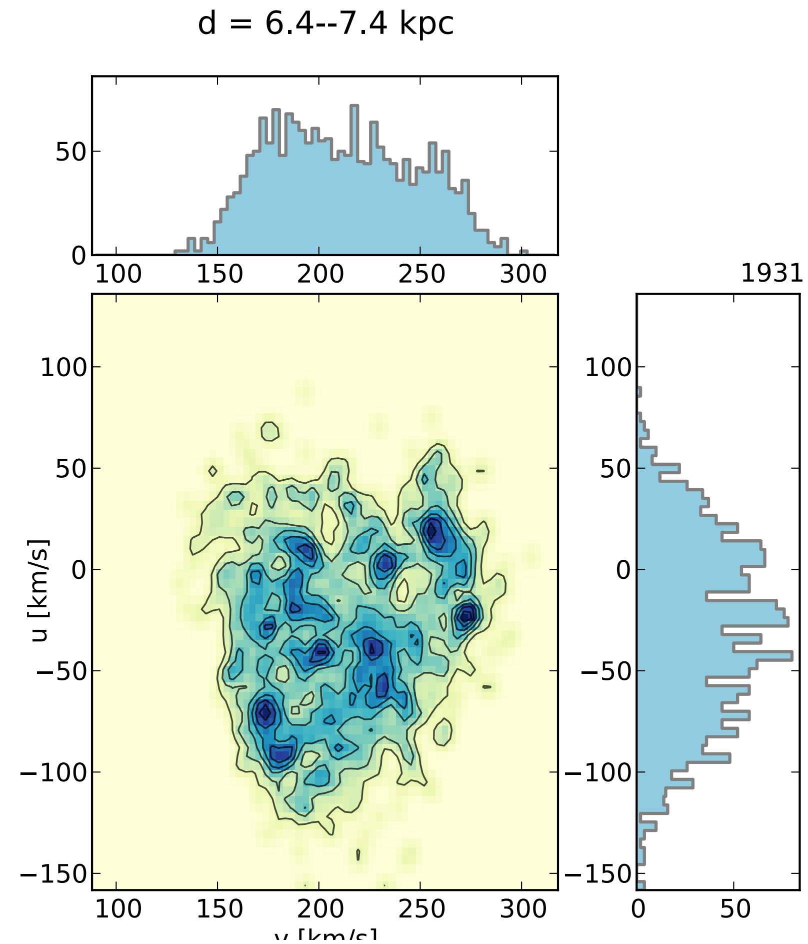
Co-rotating spirals

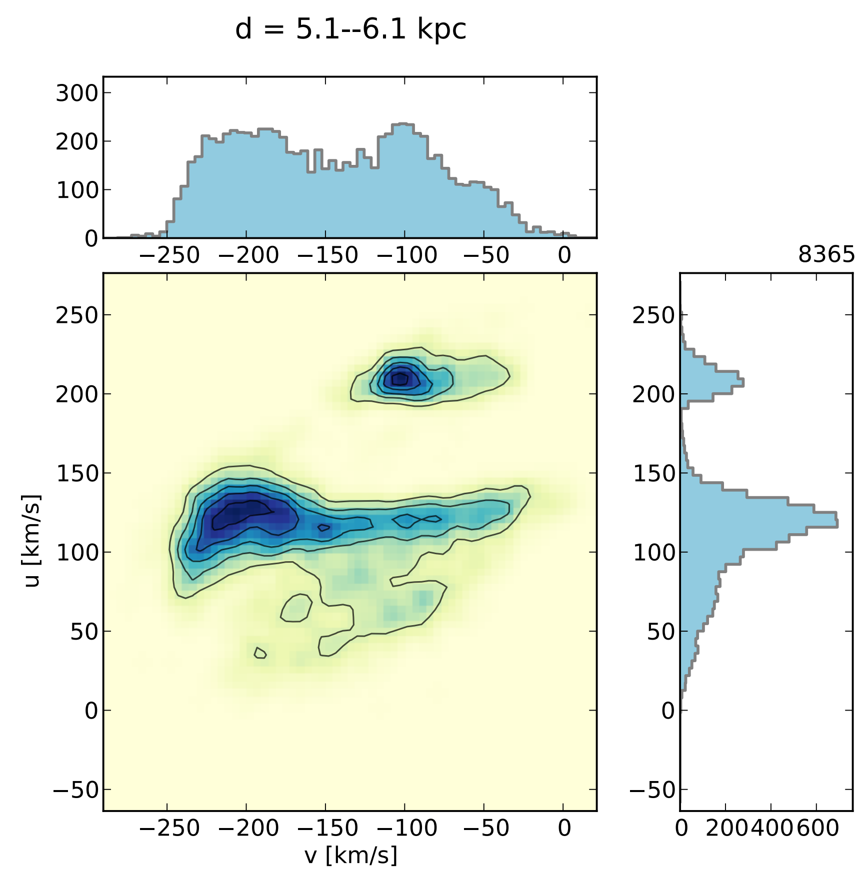
Debattista 2014





Density waves





Manifolds

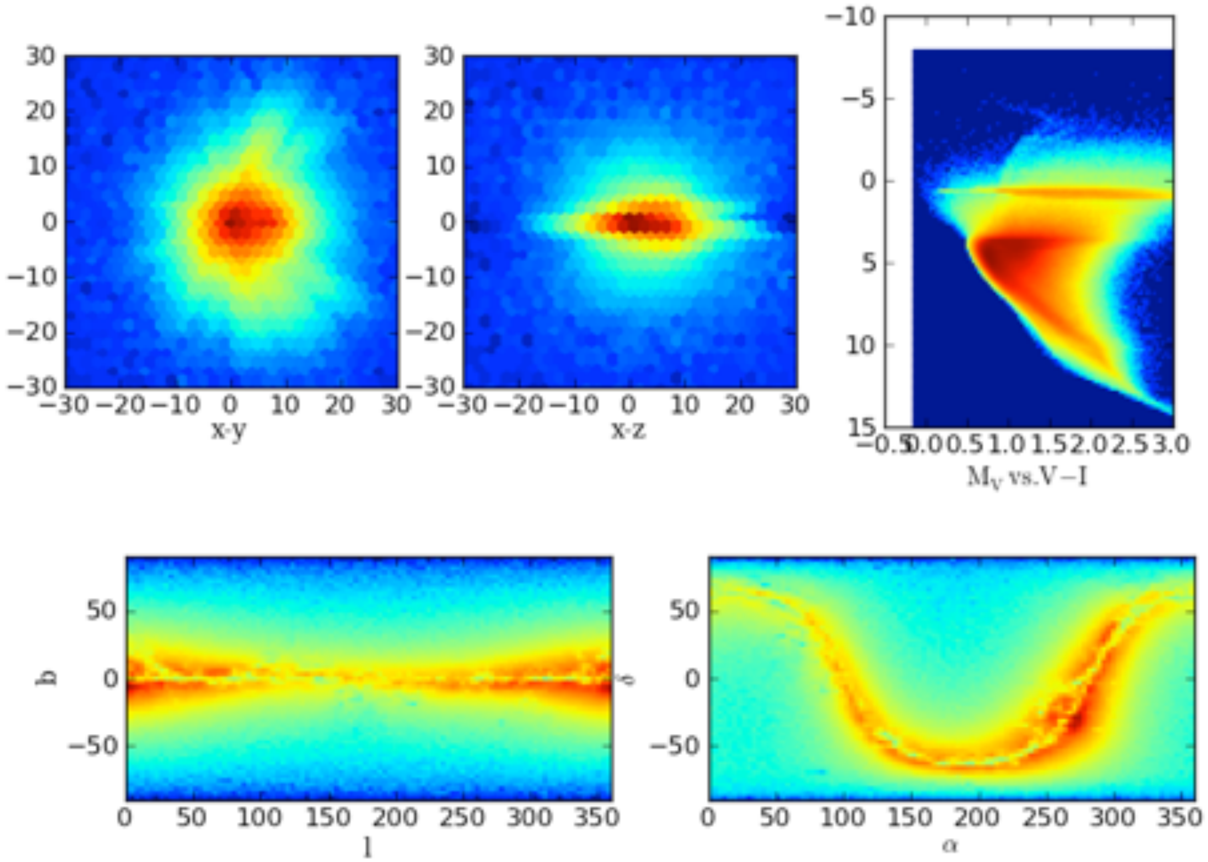
What's next?

- writing up some Gaia Challenge papers
  Local density
  Pattern speed of the bar
  Stellar motions around the different kind of spiral arms

What’s next?

More realistic Gaia mock data

Current mock: 3D extinction, Gaia erros
Missing: Multiple disk components (thick and thin disks), stellar population



More challenges

Identifying the disc plane tilt
Identifying spiral arm and pattern speed
Whole disc mass model